OHIO UNIVERSITY

Executive Summary Design Report

Senior Design

Team 4: OU BBQ
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Abstract: Background and Statement of the Problem

This paper discusses a Senior Design Project that took place in the Department of Mechanical Engineering at Ohio University. Team OU BBQ consisted of five engineering students that were presented with a problem by their client, Patricia Thomas who owns a mobile food vending service. The problem presented to the group dealt with the customer running out of product because a large enough grill could not be transported on her truck. After researching food and road safety standards, the group designed and analyzed a system that could incorporate a much larger grill and still be transported on her truck with ease of use. The end product used a hydraulic lift system that attached to the back end of the truck and lowered the grilling system to the ground so the grill could be used wherever was convenient.

Rationale: Usefulness of Device/System

The design of the mobile grilling system proves to be very different from any other grilling systems that were researched and benchmarked. Other benchmarked products intended for pickup trucks featured hitch attachment rather than a hydraulic lift table that was used in this design project. The hydraulic lift table allowed for the grill to be removed from the vehicle to allow safer and more convenient operation. A custom ash door and removable ash tray were manufactured to allow for quicker and easier cleaning of the grill. Along with a custom bumper design being installed to incorporate the lift table, a custom grill and detachable legs were designed that set it apart from any other grill found during research. Not only was the grill successfully manufactured and delivered to the customer, but the design proved to be operable by one individual and increased the amount of ribs that could be made. This directly correlated to higher profits and also a more enjoyable experience considering the customer's feedback.

Design: Solution (Overall, Cost, Ease of use and implementation, and Safety/safety features)

The materials cost of the team's design solution is broken into seven main components, which are summarized in Table 1.0 in Appendix A. The seven components are the grill grates, hydraulic lift table, grill paint, materials from Logan Welding, KCK Company and McMaster Carr, and the other estimated cost from hardware stores like Lowes. A production cost was estimated using a recommended method presented to us in one of our lectures at Senior Design. Table 2.0 in Appendix A shows the breakdown for the labor and purchased materials cost. The hours of labor to manufacture the system were estimated.

The grilling system has shown to be very easy to use and implement thus far. The customer has used the grill on several occasions over the past couple weeks at various locations and has reported no issues with the loading/unloading process. She is able to load and unload the grill in a timely manner (less than five minutes) and she has expressed that the process has gotten easier as she has learned the process better.

The grill has performed well in cooking mode as well. She has reported that the temperature is easy to moderate and that she uses less charcoal than with her old large grill. Cleaning the grill

has also proven easier than the other grills she has used. The grill grate seats are sized so that food does not build up on them and there are no other crevices for food to accumulate. The removable coal bed with handles eases leftover coal removal and the ash door makes cleaning out the ash easier than her previous grills.

Safety was a major consideration during the design process and the safety of the operator and others was considered in all modes of operation. The primary safety concern in transportation mode was that the grill unit would become detached from the truck while driving and the grill would become a hazard to other drivers. To ensure that the grill would not become detached from the truck, redundant holding methods were used. The grill is primarily held to the vehicle with two steel pins that are inserted by the operator as part of the loading process. The pins alone could hold the grill to the vehicle during transportation. To complement the primary holding method, a ratcheting tie-down strap was used to cinch the grill to the bumper. The strap also reduces vibrations in the grill lid and lift platform that could lead to eventual fatigue-related failures if not damped.

 In loading/unloading mode our primary safety concerns dealt with pinch points, sharp edges, and dropping the grill. The location of handle that operates the lift platform helps reduce the likelihood of injury while operating the lift table. The operator must stand off to the side of the table in order to raise/lower it and is therefore away from any moving parts during operation. With regard to dropping the grill, the design of the rail system makes it very unlikely that the grill would fall during operation even if the wheels were not placed in the rails. All the edges and corners of the grill and rail were rounded so the operator may come in contact with to reduce the likelihood of injury.

It was vital to make sure that there weren't any undue or excessive dangers to the operator while using the grill to cook. The lid and base both feature coiled metal handles that remain cool enough for the lid to be opened and the grill to be moved—even when the grill is operating at maximum capacity—and not cause the operator burns or discomfort. Besides being a useful cooking tool, the thermometer on the lid also gives the operator an indication of how hot the grill is (as long as the lid is shut) and whether or not it is safe to touch.

Development: Prototype (Construction quality and accuracy & Consistent and accurate function)

The prototype developed (as seen in Figure 1) was a very unique and custom design focused to aid the customer. Due to money and time constraints, the prototype was developed as the final product and had to be of high quality and function. Very few parts that make up this unique grilling system were made with high-precision machines such as a CNC mill, but the overall system had to be held to tight tolerances to make sure everything worked together.

Figure 1: Grill Prototype

The system works just as it was designed to operate. The transition from Transportation Mode to Cooking Mode takes less than three minutes with one operator. The grill is large but has shown in trial runs to heat and cook food evenly. The mounted thermometer makes it easy to see what temperature the grill is at, and the four large air vents help to control the temperature.

The system was released to the customer for use and has received nothing but good feedback. The system allows Patricia to easily transport the large grill to various locations for use. It has eliminated the need for heavy lifting, and is simple enough that the grill can be unloaded/loaded in less than three minutes.

Evaluation: Testing and Evaluation

The initial evaluation of the design concept was the failure modes and effects analysis (FMEA). In this analysis, the team considered all conceivable and reasonable failure modes and safety hazards of the current design. Alterations were then made to the design based on this analysis and then re-evaluated. The FMEA tables are given in Appendix B.

During ME-451, several FEA stress tests were performed in Algor on different system components including the bumper, the rails the grill rolls on, the grill base handle, the legs, and the lid hinges. A full description of each analysis can be located in Appendix C.

Experiments were also done in our ME-488 class to validate design choices and feasibility. These experiments included a slope lab, temperature lab, and lever force lab. A full detailed description of these experiments and their results are shown in Appendix C.

Discussion: Conclusions

The final product was delivered to the customer for final review. The unloading and loading procedure was demonstrated to her before the product was released. It was important that she had a good understanding on how the system worked so that she would be able to easily operate it on her own. At first, it was hard for her to load and unload the grill, but after a couple of times, she got the

hang of it. A Grill Manual was presented to her just in case she may forget a process. The Grill Manual is shown in full detail in Appendix D. The customer also cooked ribs on the grill before we released it to make sure all cooking-mode functions worked properly. Final feedback from Patricia has been overwhelmingly positive. She is very pleased with the ease with which she can load and unload the grill. She reports that she cannot hear any vibrations from the driver's seat while transporting the grill. With regard to cooking, she has expressed that the grill cooks very well. Specifically, she noted that it is easy to control the temperature of the grill and she can moderate the coal placement and airflow so that only a portion of the grill is utilized if need be. The optimized coal bed placement has also reduced the amount of charcoal necessary to cook the ribs as compared to her old grill which increases profits. She is now selling ribs all over Athens, Ohio with her new grilling system. She loves the grill so much that she cleans it down after every event in an effort to keep the appearance as nice as possible. Patricia has also purchased a grill cover to help increase the expected life. Based on this customer feedback and our own tests, the project has been considered to be a success.

Appendix A

1. The Table for capital expenses.
2. The Table of manufacturing and labor costs.

Table 1.0: Capital Expenses for Project

Capital Expenses	
Item	**Cost**
Grill Grates	$56.56
Lift Table	$150.00
Grill Paint	$58.69
Logan Welding	$195.69
KCK Company	$50.00
Mcmaster	$60.80
Estimated Cost	$300.00
Total:	$871.74

Table 2.0: Labor and Purchase Materials Cost for the Project

Operations	Labor Cost	Purchased Materials Cost	Total Cost
Bumper Assembly	$446.25	$119.00	$565.25
Lift Table Assembly	$337.50	$130.00	$467.50
Grill Base	$219.80	$115.00	$334.80
Grill Lid	$411.00	$75.00	$486.00
Grill Legs	$607.50	$95.00	$702.50
Final Cost:			$2,556.05

Appendix B

1. FMEA tables

Table 1.0: Transport Mode

Potential Failure Mode: Grill Security (falls off truck, extension falls down)			
	Initial Evaluation	After Action Evaluation	Actions and Comments
Severity (SEV)	5		Calculate dynamic load during breaking and turning to ensure latch is robust enough.
Probability of occurrence (OCC)	4		Make latches easily accessible and an essential step in the storage process.
Detectability (DET)	5		Develop a checklist for the owners manual.
Risk Priority Number	100		

Potential Failure Mode: Excessive Vibrations (annoying to customer, causes fatigue failure)			
	Initial Evaluation	After Action Evaluation	Actions and Comments
Severity (SEV)	2		Include damping material in the contact surfaces of the conveying platform.
Probability of occurrence (OCC)	5		Same as reducing severity.
Detectability (DET)	3		Same as reducing severity.
Risk Priority Number	30		

Potential Failure Mode: Corrosion (yields grill unfunctional before designed life)			
	Initial Evaluation	After Action Evaluation	Actions and Comments
Severity (SEV)	4		Use corrosion resistant materials and use weather resistant coatings. Make parts that will eventually corrode replaceable and develop a proper cleaning procedure.
Probability of occurrence (OCC)	3		Same as reducing severity.
Detectability (DET)	1		Develop a visual inspection as part of regular maintenance.
Risk Priority Number	12		

Table 2.0: Unload - Load Mode

Potential Failure Mode: Lift Mechanism (seizes, joint failure, etc)			
	Initial Evaluation	After Action Evaluation	Actions and Comments
Severity (SEV)	5		Run FE analysis to validate the strength of the four-bar mechanism under a static load.
Probability of occurrence (OCC)	3		Specify maintenance schedule and proper use
Detectability (DET)	3		Specify proper operation, visual inspections, and regular maintenance
Risk Priority Number	45		

Potential Failure Mode: Pinch Points / Sharp Edges			
	Initial Evaluation	After Action Evaluation	Actions and Comments
Severity (SEV)	4		Eliminate as many sharp edges and corners as possible in design
Probability of occurrence (OCC)	4		Same as reducing severity
Detectability (DET)	1		Paint unavoidable sharp edges or corners yellow
Risk Priority Number	16		

Potential Failure Mode: Control Issues (falls off truck, rolls away, leg failure)			
	Initial Evaluation	After Action Evaluation	Actions and Comments
Severity (SEV)	4		Use of a boxed frame for the grill to increase strength. Locking casters will be used to prevent the grill from rolling away. Make prototype bracket and leg assembly to make sure leg can be inserted easily.
Probability of occurrence (OCC)	3		Include motion limiting elements in our design (tracks, stoppers, and brakes)
Detectability (DET)	4		None
Risk Priority Number	48		

Table 3.0: Cooking Mode

Potential Failure Mode: Falls / Tips (rolls away)			
	Initial Evaluation	After Action Evaluation	Actions and Comments
Severity (SEV)	5		None
Probability of occurrence (OCC)	3		Maximize width of base, make center of gravity as low as possible, locking casters
Detectability (DET)	5		None
Risk Priority Number	75		

Potential Failure Mode: Burns			
	Initial Evaluation	After Action Evaluation	Actions and Comments
Severity (SEV)	3		None
Probability of occurrence (OCC)	3		Include heat resistant materials for high contact areas
Detectability (DET)	1		Grill thermometer
Risk Priority Number	9		

Potential Failure Mode: Insufficient or Excessive Airflow			
	Initial Evaluation	After Action Evaluation	Actions and Comments
Severity (SEV)	4		None
Probability of occurrence (OCC)	3		Calculate optimal air flow to design the air vents
Detectability (DET)	1		Grill thermometer
Risk Priority Number	12		

Potential Failure Mode: Difficult to Maneuver / Wheels Seize			
	Initial Evaluation	After Action Evaluation	Actions and Comments
Severity (SEV)	3		None
Probability of occurrence (OCC)	3		Include four swivel casters and specify maintenance
Detectability (DET)	3		Visual inspections and general maintenace
Risk Priority Number	27		

Appendix C

1. ME-451 Verification Study on C-channels (James Harris)
2. ME-451 Parametric Study on C-channels (James Harris)
3. ME-451 Verification Study on hinges (Daniel Shapiro)
4. ME-451 Parametric Study on grill legs (Aaron Shelly)
5. ME-451 Parametric Study on the bumper (Colton Shoemaker)
6. ME-451 Parametric Study on grill base (Shad Williams)
7. ME-488 Final Report

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Methods

The problem chosen for this verification study includes the analysis of a channel. The C channel pertains to the OU BBQ Senior Design project and plays a main role in the structural integrity of the lift system. The C channel will serve as a rail for wheels to ride in, therefore bearing some of the weight of the grill in the extended position. To imitate this real life application, a C-channel was constructed in SolidEdge with the dimensions shown in Figure 1. The geometry and dimensions reflect the material that will be purchased for the project. The 15.25 in length reproduces the amount of material that will be hanging off the truck, therefore holding the load.
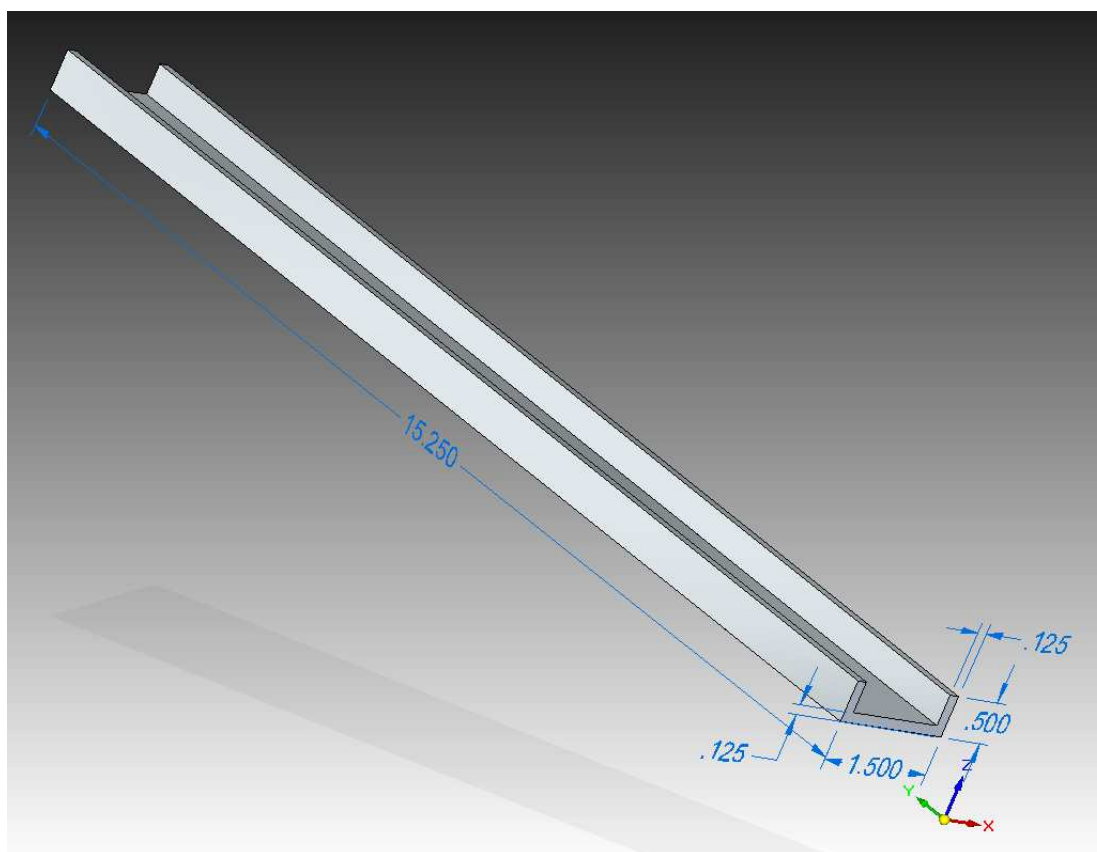
Figure 1 – C- Channel with dimensions

The SolidEdge model was then imported into Algor to perform the finite element analysis of the channel with one end being completely fixed and the other end having a 100lb load in the vertical direction as can be seen in Figure 2. ASTM 36 Steel was chosen to also mimic the material being used in the project.
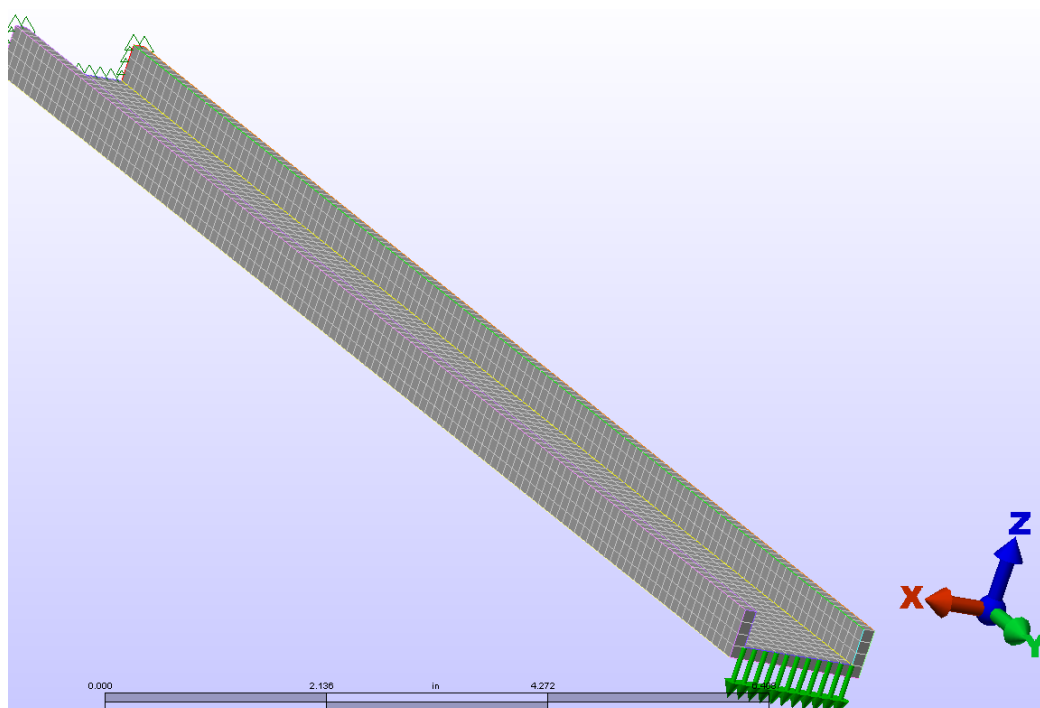
Figure 2- Loads and constraints placed on C-channel

After the loads and constraints were applied, the analysis was performed using solid elements with mesh sizes ranging from 0.125-.04 inches. The value of .04 inches was chosen because this value is one third the size of the smallest length in the part which is one eighth of an inch. As can be seen in Table 1, the von Mises stress maximum reached was 118kpsi. The value also converged with a percent difference of 2% and exhibited a maximum displacement of .78 inches. To take the verification another step further, plate elements were then modeled using the same mesh sizes and placed into Table 2. The plate elements also converged at 118kpsi and a maximum displacement of .79 inches. Although the two methods of meshing began with variations, the two converged at the same maximum von Mises stress.

Data

Table 1

Mesh Size (in)	Number of Surface Elements	Degrees of Freedom	Max. Aspect Ratio	Displacement(in)	Member	σ_{MAX} ALGOR (PSI)	Percent Difference
ASTM 36 Steel				Solid Elements in Algor			Edge Load:100lbs
0.125	4674	13908	1	0.771	fixed	112,172.00	9%
0.1	10123	30192	4.3	0.771	fixed	102,783.00	9%
0.075	19176	57246	1.30	0.78	fixed	112,991.00	2%
0.05	52630	157380	1.36	0.778	fixed	115,670.00	2%
0.04	85568	256032	1.04	0.777	fixed	118,187.00	

Table 2

Mesh Size (in)	Number of Surface Elements	Degrees of Freedom	Max. Aspect Ratio	Displacement(in)	Member	σ_{MAX} ALGOR (PSI)	Percent Difference
ASTM 36 Steel		Midplane Plate Elements					Edge Load:100lbs
0.125	2091	12444	1.5	0.79	Fixed	106,745.00	1%
0.1	3213	19152	1.61	0.79	fixed	107,882.00	2%
0.075	5712	34104	1.82	0.79	fixed	109,705.00	4%
0.05	12240	73200	2.29	0.79	fixed	114,415.00	4%
0.04	19100	114300	2.59	0.79	fixed	118,700.00	

The data taken from the analysis performed can be seen in Figure 3 and Figure 4. The stress maximum occurred at the point nearest to the fixation of the wall which is where I hypothesized the max to occur.
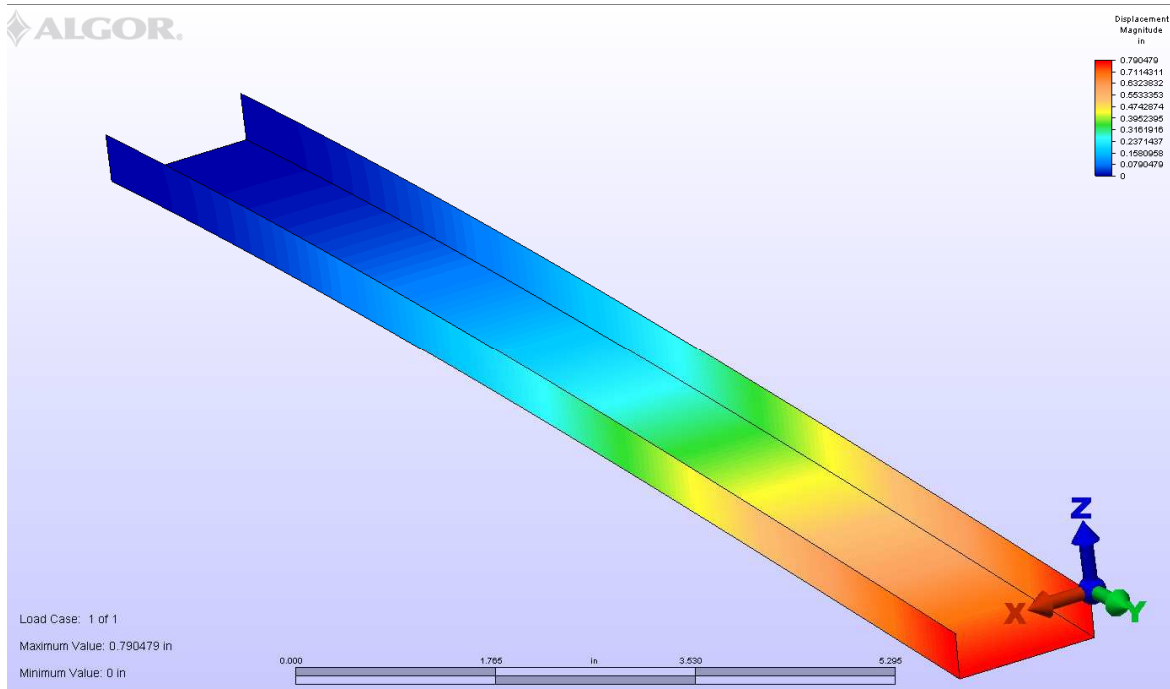
Figure 3 – C-channel with maximum displacement
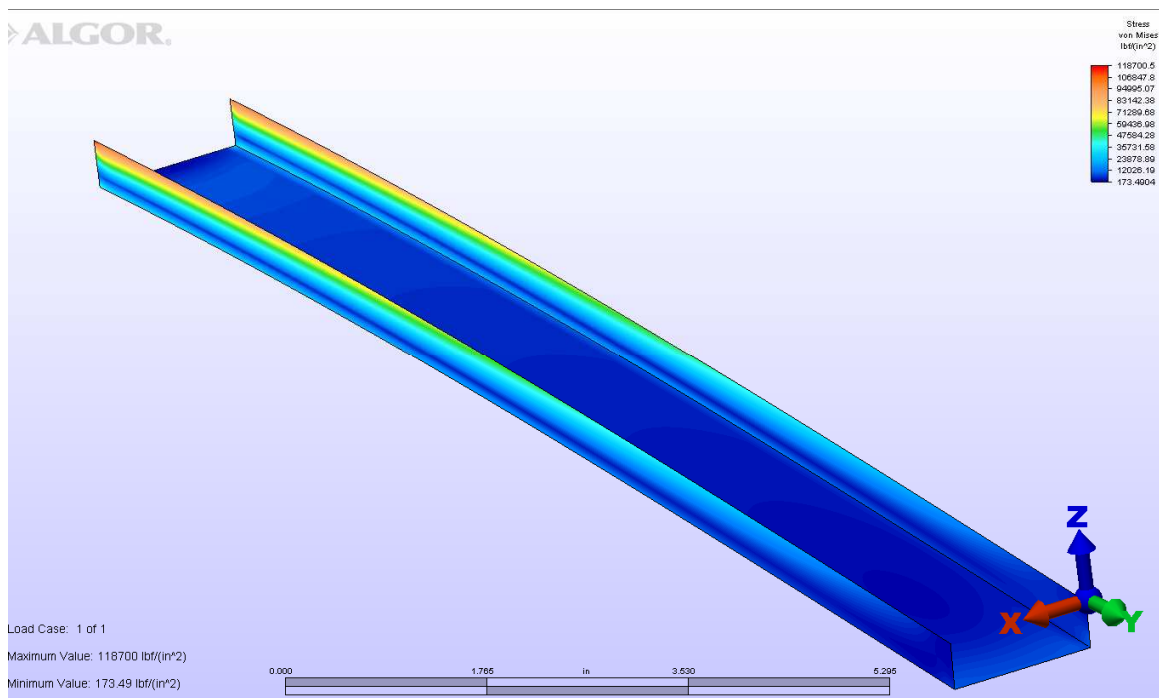
Figure 4 – C-channel with von Mises stress maximum

The last step in this verification problem can be concluded with a hand calculation of the C-channel. After viewing the hand calculations, the stress maximum was chosen to occur near the point of fixation giving a maximum moment of 1525 in-lb. To achieve the stress maximum, the area moment of inertia needed to be calculated. After all calculations were completed, a stress maximum was equated to be 104kpsi. In comparison to the Algor results, the hand calculations leave a percent

difference of 18%. The reason for this error may come into account when applying the constraints in Algor because edge loads were used. All calculations can be seen below for the hand calculations. From this verification, I was able to tell that the C-channel alone would not be strong enough for our application and therefore needed to be optimized.

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ME 451 – Parametric Study

After dealing with issues of complexity with early designs of the fork assembly in our lifting process, a redesign needed to be incorporated. The group decided that C-channel needed to be used for our application. After modeling the C-channel in SolidEdge and importing the model into Algor, I found that the C-channel wasn't near strong enough by itself. Therefore I needed to optimize the fork system to withstand the weight of the grill while keeping the C-channel geometry. To do so, several designs were modeled in SolidEdge and each was imported into Algor. The models were then tested to withstand a distributed load and if the max stress was higher than the yield point than another design was needed. The variables that changed in the process were the height and width of a brace that was placed under the C-channel.

To imitate the forces and constraints in real life, some analysis plates were added to the original C-channel assembly. By adding these, I was able to constrain the first 17.25 inches of the bracket in the Z direction because the cart's tabletop would be in contact with this surface. The brackets will be welded to the C-channel and then the whole assembly will then be bolted to the table. I changed the contact between the brackets and the C-channel to welded instead of bonded. The bolt holes were fixed in all directions to reproduce the bolts being inserted. A distributed load of 100 pounds was then put on the other analysis plate that would overhang the table. All of these constraints can be seen in Figure 1.
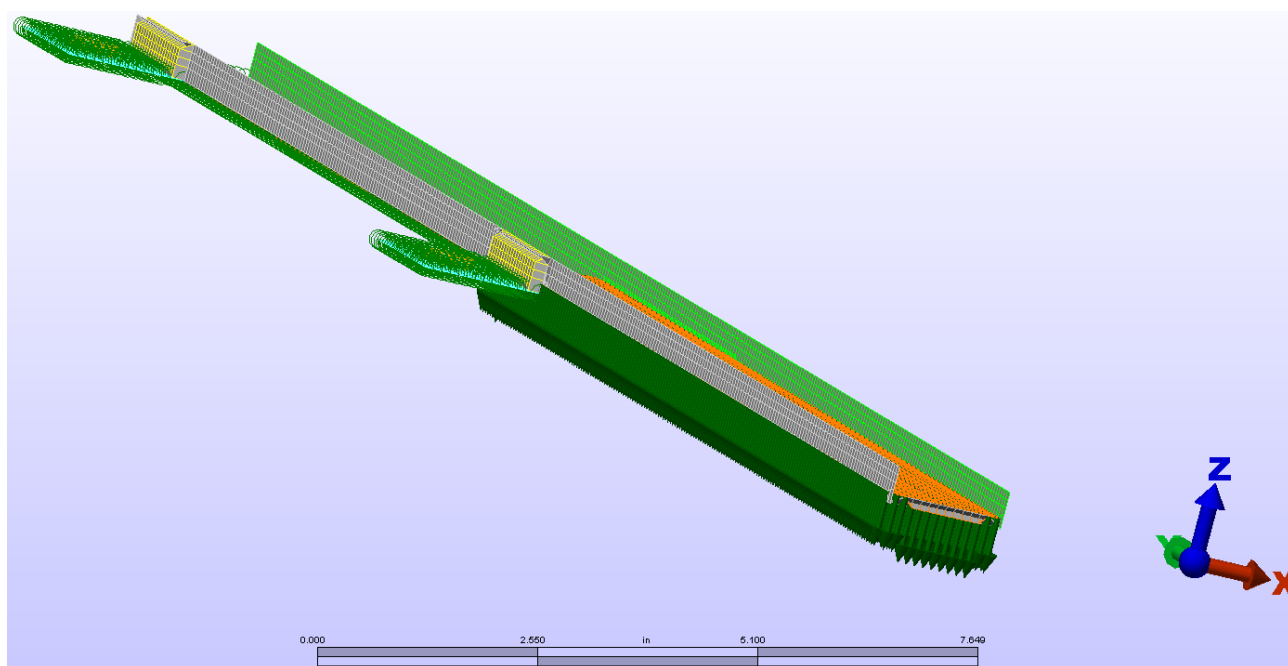
Figure 1 – Loads and constraints on C-channel

As can be seen in Figure 2, the analysis seemed to show poor results because the analysis plate ran through the part. After changing the contact between the plate and the C-channel to bonded instead of surface contact, the analysis seemed to work.
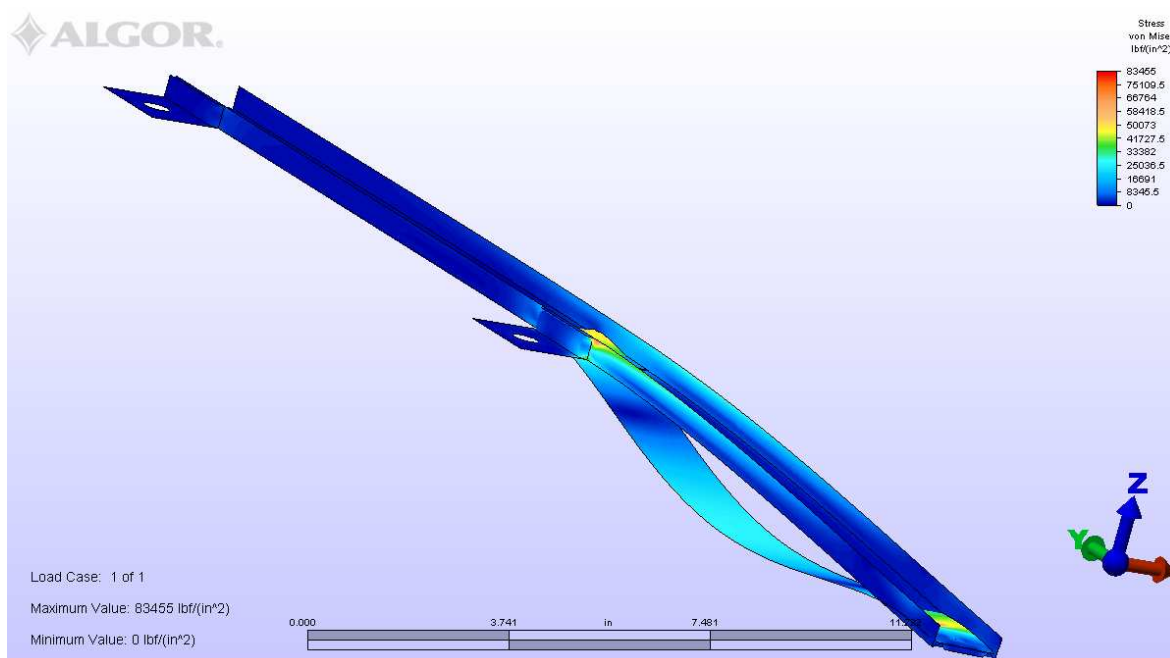
Figure 2 – Misuse of contacts in first trial

In Figure 3, the bonded contact was used and the analysis shows a stress maximum at the top portion of the C-channel near the table connection. This maximum of 63kpsi proved to be much higher than the yield strength of ASTM 36 steel at 36kpsi.
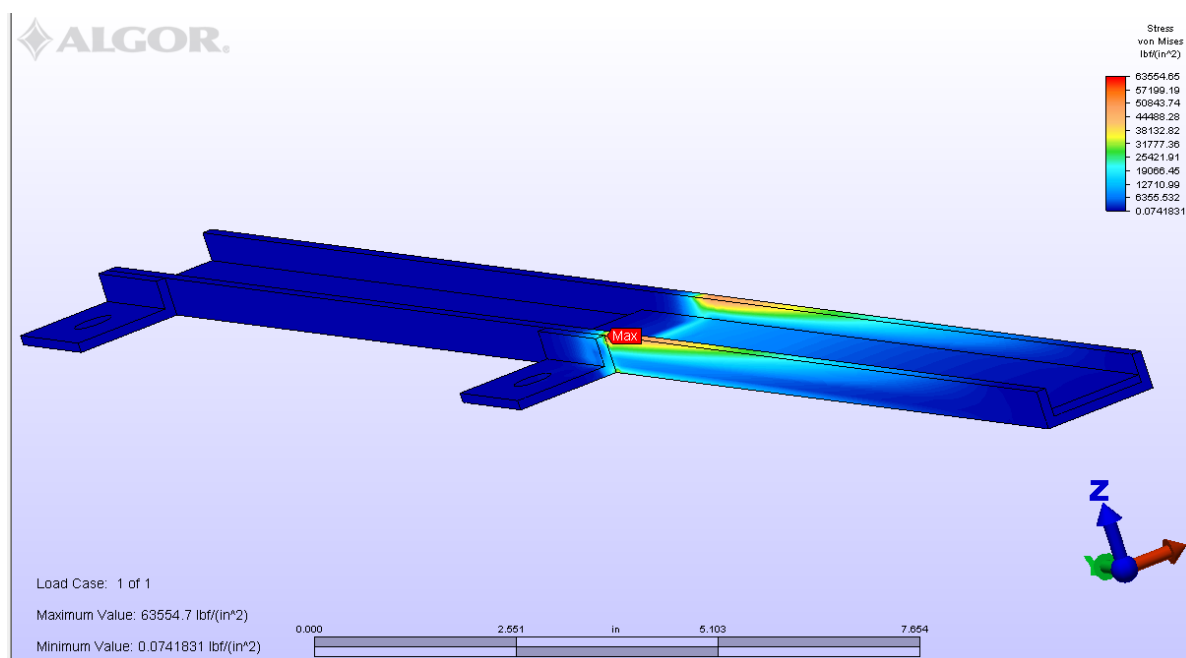
Figure 3 – C-channel with stress maximum shown

The next step in the process of optimization was to insert a sort of rib to the bottom of the C-channel that overhung off the table cart. The thickness of this rib was chosen to be 1/8" because this would be extra steel off of our excess used for the grill. The rib would be welded along the bottom to add stability. The height of the rib was chosen to be ½". As Figure 4 shows, the stress maximum was now at the bottom of the rib where it would be in contact with the table. This means the force has become compressive on the bottom instead of in tension on the top of the C-channel. The stress maximum lowered to 37kpsi yet this was still not strong enough to hold the weight being placed on the C-channel.
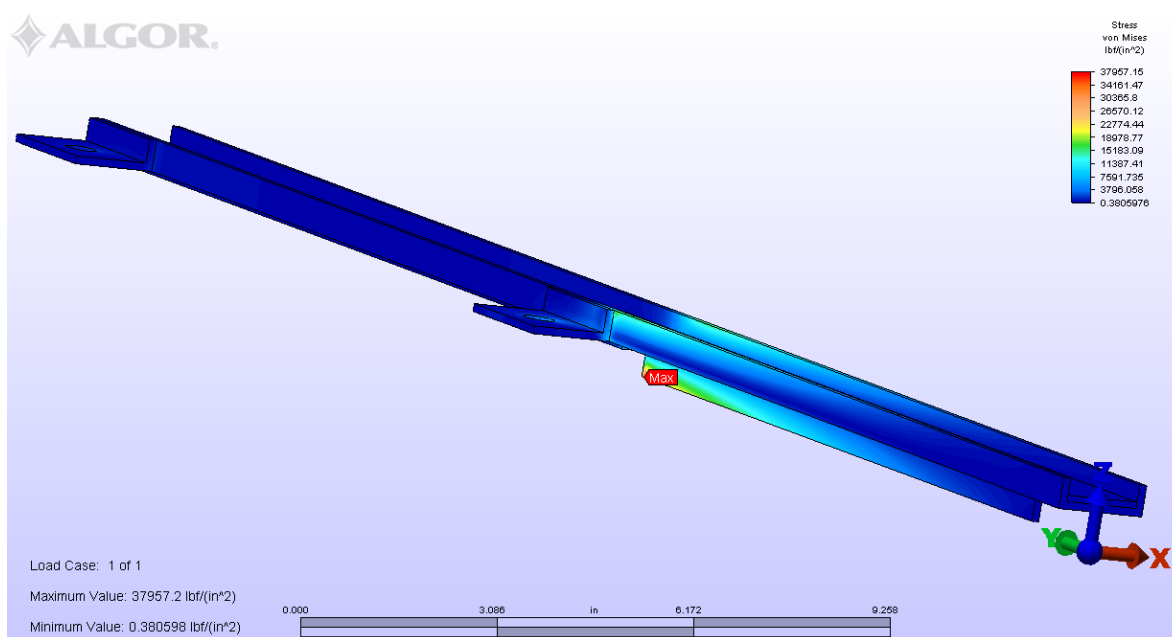
Figure 4 – C-channel with rib stress analysis maximum

After analyzing the table's dimensions the maximum height of the rib could only be 1.375 inches. The length of the rib could only extend from the table to the other end of the C-channel were a bracket was to be mounted for stopper system. In turn, I made the end closest to the table the maximum height I could use and tapered the steel rib to the other end for aesthetic and safety reasons. After modeling this in SolidEdge, a stress analysis was run and the results proved to work out well. The stress maximum had moved to the connection of the C-channel and the rib which could be reduced even more with a fillet inserted rather than a sharp corner. Figure 5 shows the stress analysis of this design and proved to be the most optimal design.
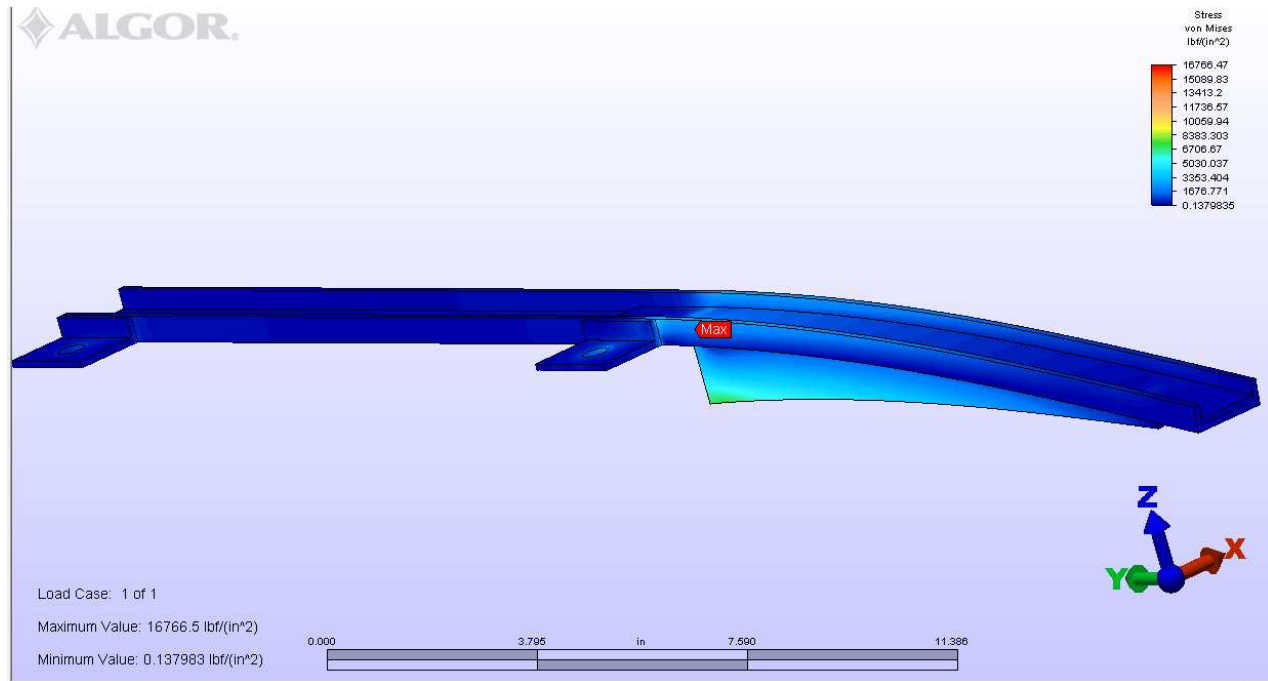
Figure 5 – Tapered Rib design in stress analysis

After running the first mesh and observing the stress maximum to be 5kpsi, a convergent study was held to assure that the design was proper. In Table 1, one can see that the stress converges around 16kpsi which is well below the yield point. Although this may seem over engineered, one must take into account the misuse of the system by the customer. Someone that simply leans on or loads the system with more than 200 lbs could be a probable occurrence. Therefore this design will make the system much safer if this occurs.

ASTM 36 Steel		Distributed load of 100 pounds				
Mesh Size (in)	Number of Surface Elements	Degrees of Freedom	Max. Aspect Ratio	Member	σ_{MAX} ALGOR (PSI)	Percent Difference
0.5	3344	9680	28.35	triangle	5,334.00	5%
0.4	3895	11251	23.67	triangle	5,080.00	37%
0.3	5505	16004	34.29	triangle	7,408.00	7%
0.2	8870	25710	10.1	triangle	7,921.00	52%
0.1	37702	110003	35.5	triangle	13,451.00	12%
0.08	72686	213146	7.1	triangle	15099	10%
0.06	126281	370495	5.92	triangle	16,766.00	

Table 1 – Convergent study of chosen design

In conclusion, the design chosen will be the one that is used for our Senior Design project. After reanalyzing the system, the manufacturing leaders will be sure to make corners rounded near the table to reduce the stress concentration that occurs at this point. This design will also be cost

effective because other material will not need to be purchased. Although many variables could be taken into account with this parametric study, the variables changed were ones that could easily be accomplished with the resources available. A simple rib added to bottom of the C-channel solved the problem of holding the load that was being applied.

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FE Verification

Introduction:
While finite element analysis is a powerful tool for the modern engineer, it is important to understand what is being done by the computer so that one can ensure that the conditions that are set up in your FE program simulate the real world scenario you desire. To this end of verifying the results of a finite element analysis, I took the opportunity to compare the theoretical results of our grill's hinge under loading conditions and compare them to the ALGOR results.

The Test Scenario:
The scenario is fairly basic, a simple brass pin is loaded in shear and the stresses experienced by the pin must be less than the yield point. The hand calculations for this situation may be found bellow in portable document format. The manufacturer of this hinge rates the system for 300 lbs, so in order to ensure that this a valid rating the simulation was run at the rated maximum load.

Simulation Conditions:
In order to simulate the loading conditions for the finite element analysis one half of the pin was modeled in Solid Edge. After the pin was imported into ALGOR the part was run at a 100% automatic sized mesh so that the materials and loading conditions could be set.

The following conditions were set for the pin and can be seen in Figure 1:

- Along the plane where the pin was cut in half Z axis symmetry conditions were set.
- A surface load of 300 lbs was set on one half of the pin's top surface.
- On the other side of the pin, a 'pinned' surface boundary condition was placed to emulate the pin being held still from translation, but not rotation by one of the hinge pin holders.
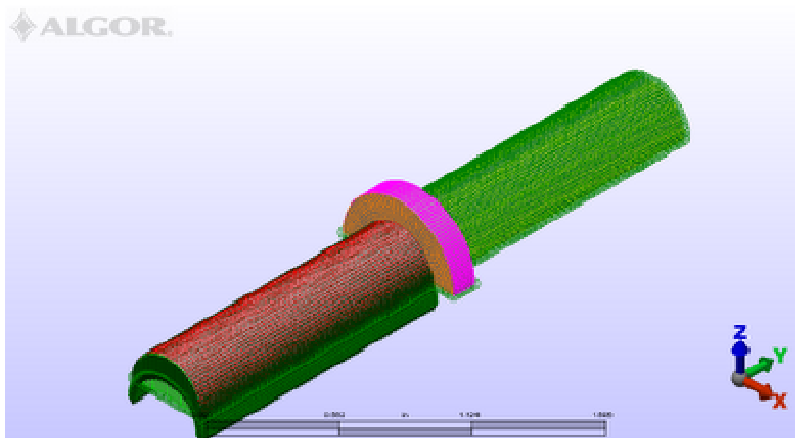
Figure 1: Setup of Hinge Pin Loading Condition and Constraints

Results:

Table 1: Summary of FE Analysis

mesh size (percent of auto)	nodes	dof	max stress	Percent diff
50	3780	9280	1959	
40	7381	18740	2151	-9.343065693
30	18141	48125	2381	-10.15004413
25	31624	85429	2554	-7.011144883

Table 2: Percent Error Comparison of FEA to Analytic Solution

Column1	Stress	% Error
Analytic	2.3144	0
50	1.959	15.35603
40	2.151	7.060145
30	2.381	2.877636
25	2.554	10.35258
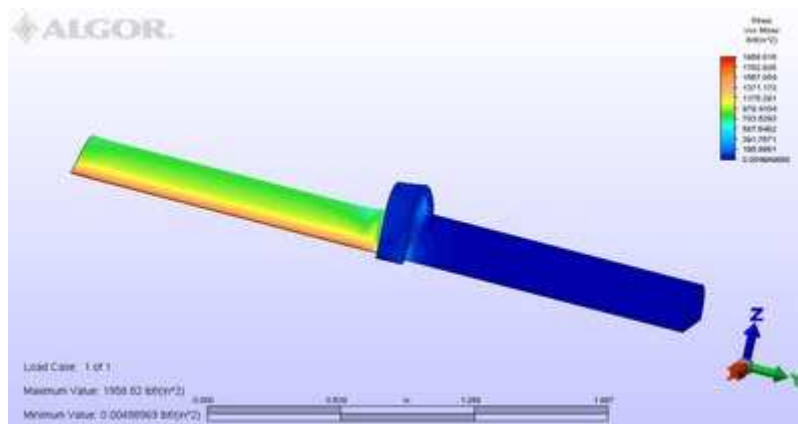
Figure 2: Results of 50% Automatic Size Mesh
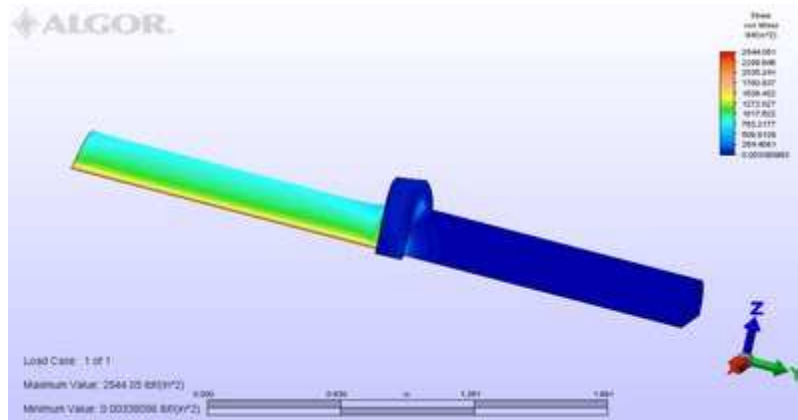
Figure 3: Results of 25% Automatic Size Mesh
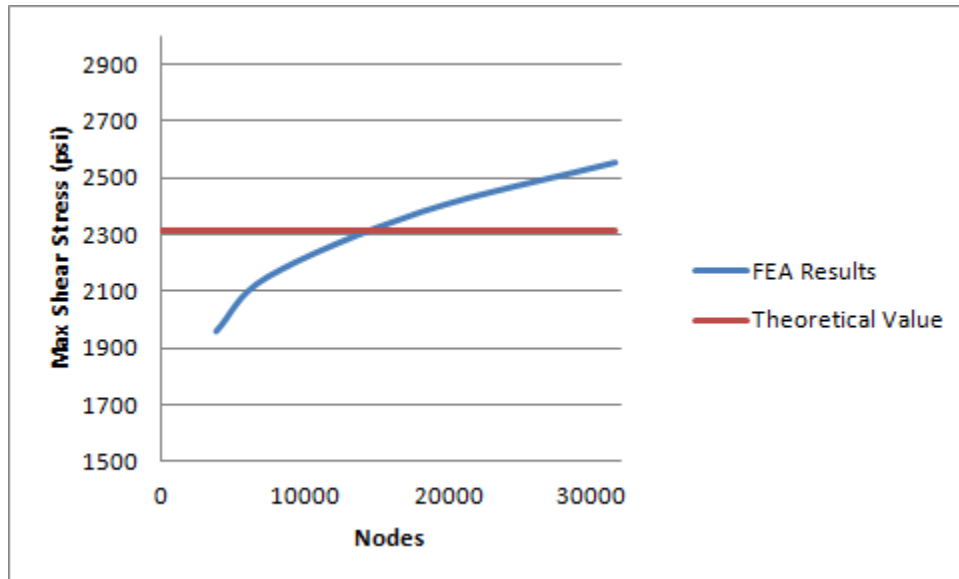
Figure 4: Graph of Shear Stress Vs Nodes

Conclusion:

From the comparison of the finite element analysis to the results of the theoretical hand calculations it can be seen that maximum stresses the hinge pin will be exposed to should be around 2.3-2.5 ksi.

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FE Parametric Study

   The goal of my parametric study was to determine what size tubing for the grill leg assembly would be adequate to withstand a worse-case load scenario (experience stresses below the yield stress) and minimize overall weight. Taking material cost, availability, and manufacturability into consideration, the tubing sizes were narrowed down to either 2"x3", 1/8" thick or 2"x2", 1/8" thick 6061 aluminum tubing.

   It was decided that the worse-case loading scenario we could reasonably expect our grill to withstand is a 100 lb horizontal load (depicted in Figure 1 below and includes a 1.5 factor of safety). This would simulate if the customer pushed the grill into an object and then leaned against it. In all analyses, the weight of the grill (not including legs) was given a worse-case-scenario weight of 181.5 lbs which includes a factor of safety of 1.5.
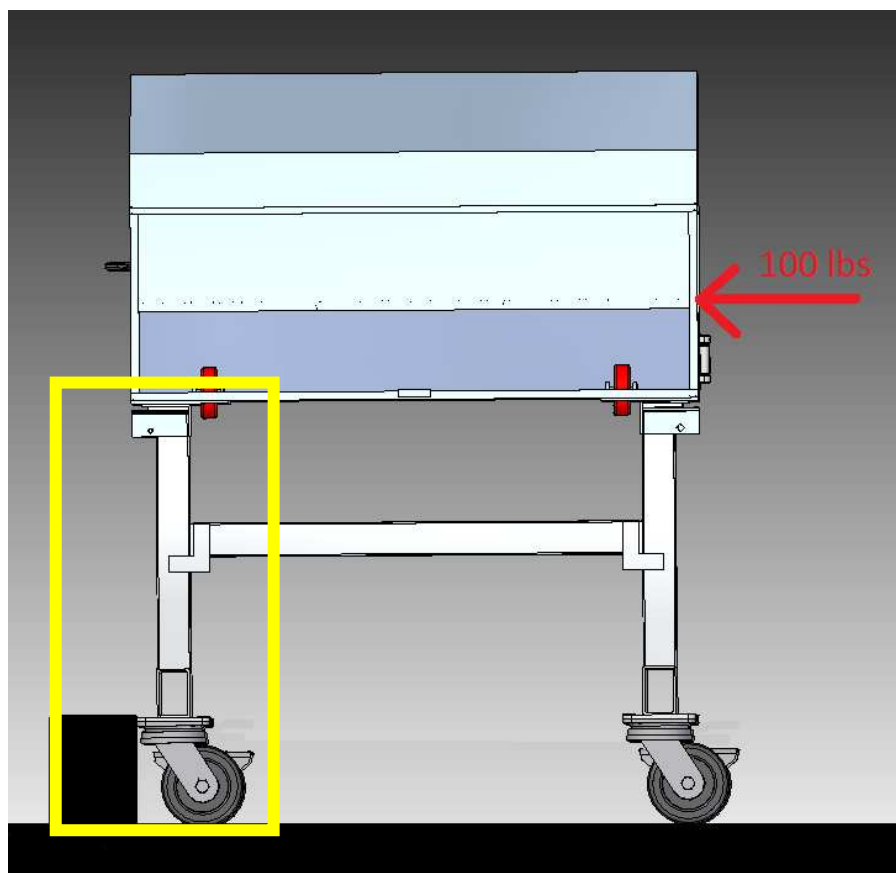
Figure 1: Grill loading Scenario

Since the leg assembly is large in scale, it was important to reduce the model size as much as possible to maximize the models economy. There is one plane of symmetry that can be used, but

even this doesn't reduce the model size sufficiently. To reduce the model size even more, the left leg (highlighted in yellow in Figure 1) was focused on.

In order to determine the internal reaction forces in the cutting planes that would be utilized (represented by points A and B in Figure 2), a static beam analysis was performed in ALGOR. The constraints and deflected model are shown below in Figure 2.
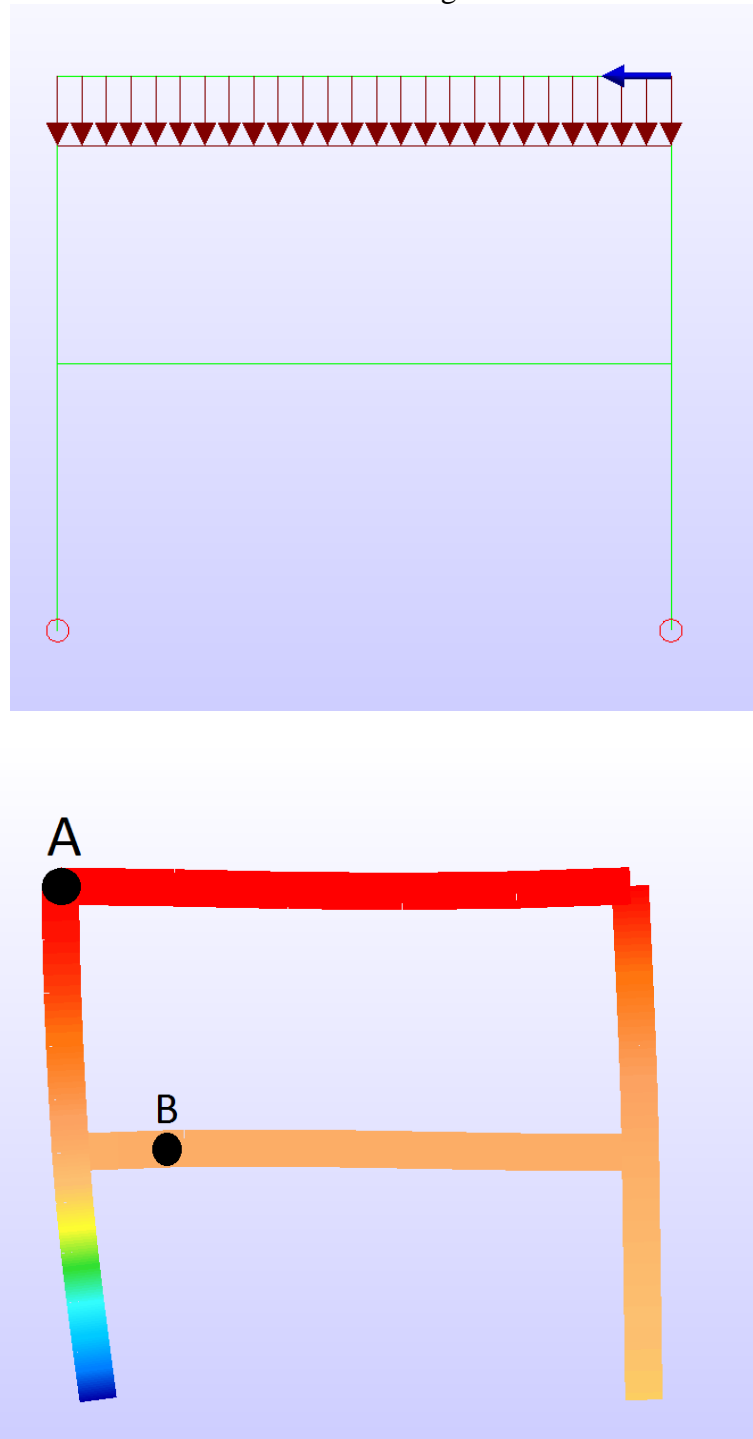
Figure 2: Beam Analysis of Leg Assembly

The shear, axial, and moments at locations A and B were recorded and applied to a cut solid-element model in ALGOR as depicted below in Figure 3.
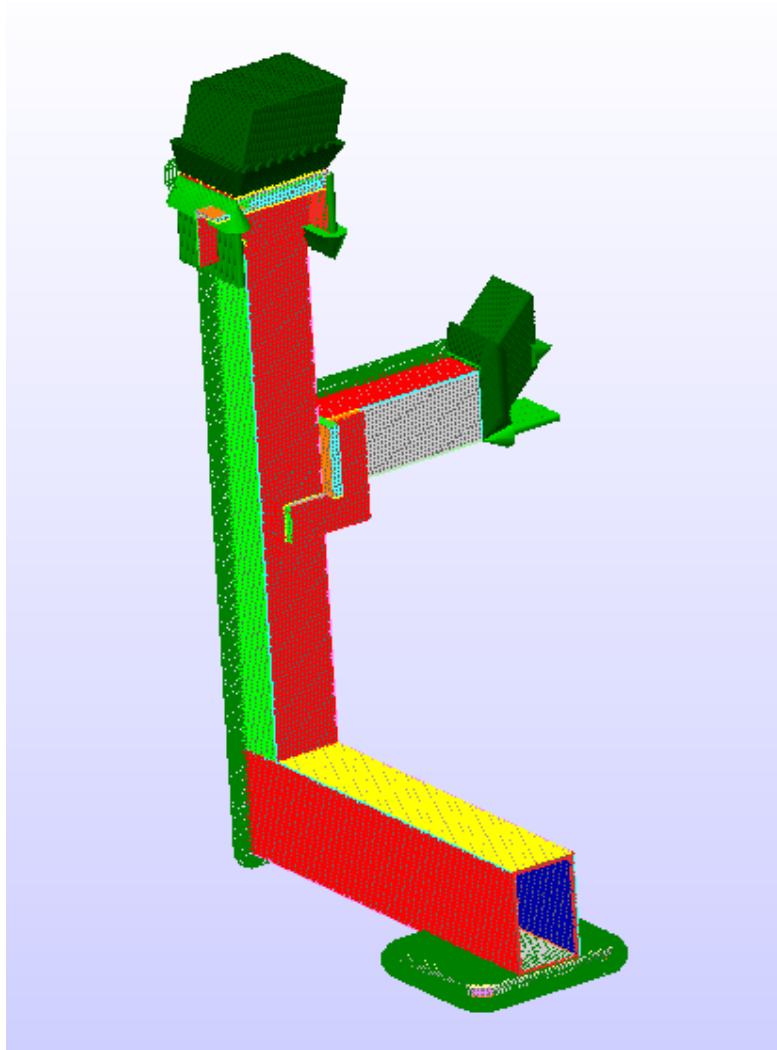
Figure 3: Meshed Solid Model with Applied Forces and Constraints

The analysis was performed with a 0.250, 0.125, and 0.100 inch absolute mesh size on an assembly utilizing 2"x3" tubing as well as an assembly utilizing 2"x2" tubing. Due to the method of attachment of the bracket and leg link, the model was under constrained when all of the surfaces in contact were analyzed as such. In order to get the analysis to run without any warnings, several of the surfaces in the leg link had to remain bonded. These artificially bonded surface contacts created stress artifacts that had to be eliminated. Since the main purpose of the study was to analyze the integrity of the tubes, the bracket and leg link parts were hidden so that the stresses in the tubes could be observed. The results of the FE analysis are presented in Table 1 below.

The maximum von Mises stress in the 2"x3" tubing converged to approximately 32,000 psi and the maximum von Mises stress in the 2"x2" tubing converged to approximately 33,000 psi. Convergence plots can be seen in Figure 4 and Figure 5. The maximum stress occurred,

consistently, in the same location on the vertical leg tube where the leg link catch is welded for both tube sizes and all meshes. The stress distribution and location can be viewed in Figure 6 below.

Table 1: FEA Results

2x3 inch tubing				
Mesh Size (in)	Degrees of Freedom	Max Aspect Ratio	Max Stress (Von Mises) PSI	Percent Difference
0.25	50,767	21.7	16,819	---
0.125	116,371	5.2	24,680	37.9
0.1	248,989	8.1	30,822	22.1
0.08	397,689	9.5	31,686	2.76

2x2 inch tubing				
Mesh Size (in)	Degrees of Freedom	Max Aspect Ratio	Max Stress (Von Mises) PSI	Percent Difference
0.25	44,218	21.9	17,417	---
0.125	96,794	12.5	25,586	38.0
0.1	204,546	7	31,877	21.9
0.08	325,975	7.5	32,928	3.24
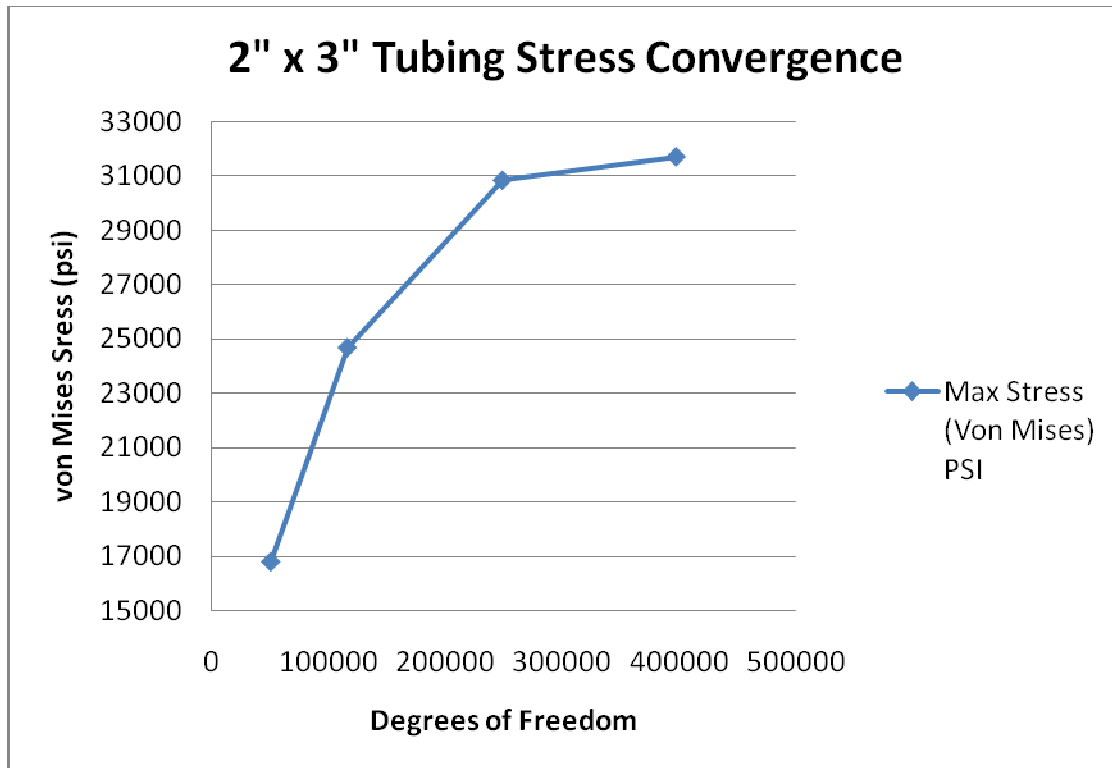
Figure 4: 2"x3" Stress Convergence Plot
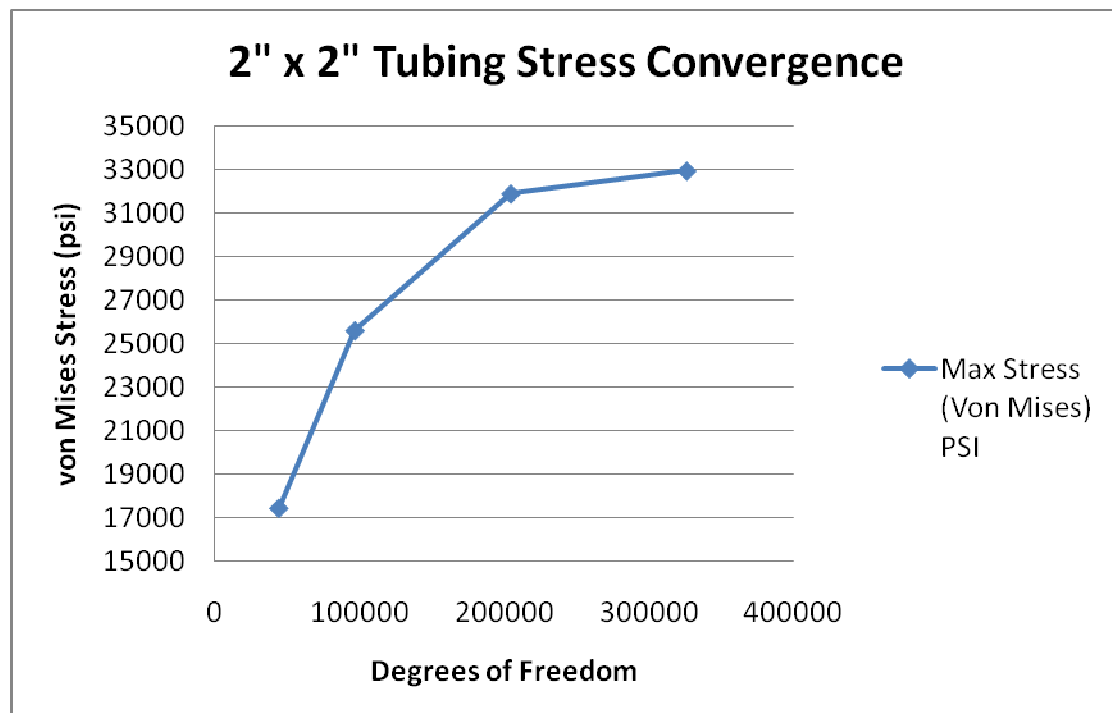
Figure 5: 2" x 3" Stress Convergence Plot
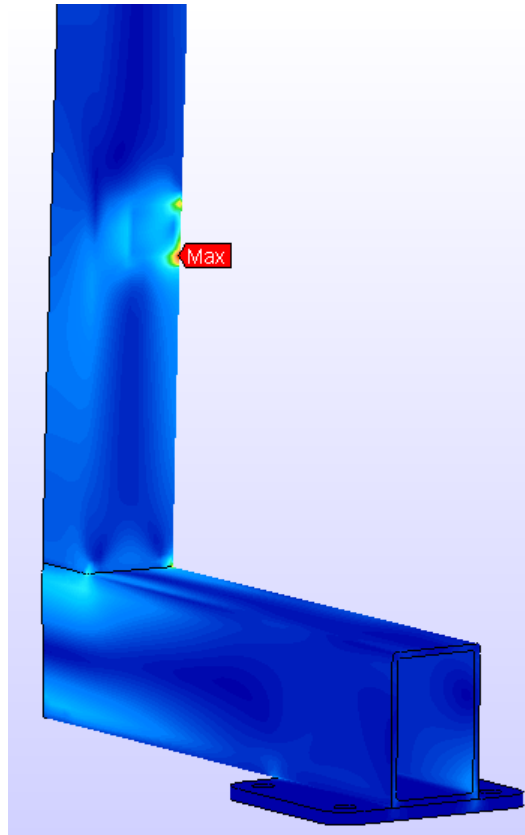
Figure 6: Maximum Stress Location

Conclusion:

       Based on the results from this parametric study, it was decided that 2"x2", 1/8" thick, 6061 aluminum tubing will be the best choice for our design. The 2"x2" tubing experiences stresses that are negligibly larger than the 2"x3" tubing. Both sizes of tubing come very close to failure under this load condition. This was a positive outcome considering the loads applied included a 1.5 factor of safety. This suggests that our design is adequate, yet not over designed. Using 2"x2" tubing instead of 2"x3" tubing will take approximately three pounds off of our entire leg assembly weight (from 24.6 lbs to 21.9 lbs). The reduction in leg assembly weight is critical seeing as our customer will carry the leg pieces from inside her truck to the back of the truck to assemble them.

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3-9-10

In my group I have been working extensively on modeling all the current hardware on the truck. I modeled the bumper and all of the brackets that help support the bumper and attach it to the frame of the truck. As a group we got various dimensions from the bumper of the truck that I would need to model it as accurately as possible. We assumed that most of the bumper was steel; this being all of the brackets and members used to support the bumper and attach the bumper to the frame of the truck. We assumed that top of the bumper was aluminum diamond plate because it did not provide any real structural support.

My goal is to design a system to attach our hydraulic lift cart to the bumper of our customer's truck. I wanted the cart to be bolted to the bumper in some fashion so that it could be removed whenever needed for repairs or anything else. I had to keep the cart as low and close to the bumper as possible; if it was raised to high we would be wasting the effectiveness of having a moveable cart, and creating un-need moments. So my design consists of a 'base' that will be mounted to the bumper, the cart can then be bolted to the base.

This parametric study will focus on designing the 'base' and how it will be mounted to the bumper. The key here is to keep the design simple and effective. I do not want to make this overly complicated to manufacture, understand, or implement, mainly because most of our time will be spent manufacturing the grill. I also don't want to design something that will have a relatively high factor of safety such as a F.O.S of 5; I don't see how that would be beneficial either.

Figure 1 below shows the current bumper arrangement. It would be ideal if I could mount the cart in the center of the bumper, however we plan to use the bumper to store an existing propane tank as well. So the cart will have to be mounted on the driver side, while leaving room for the tail lights to be visible.
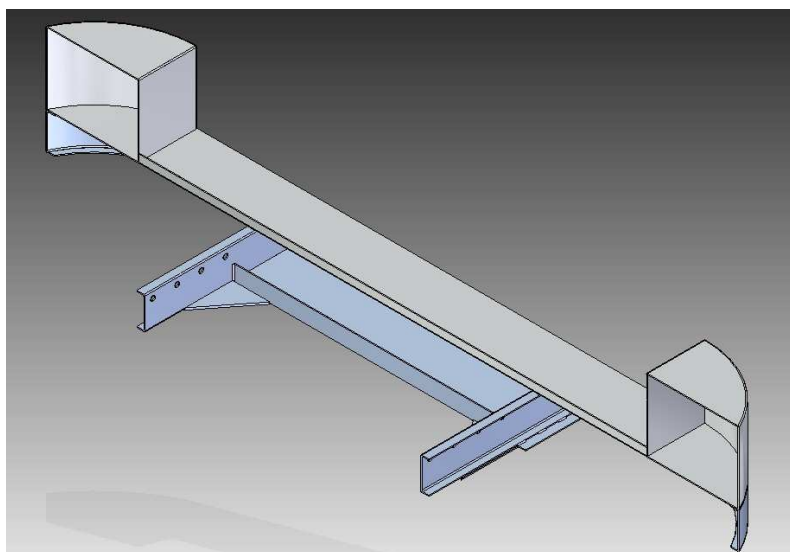

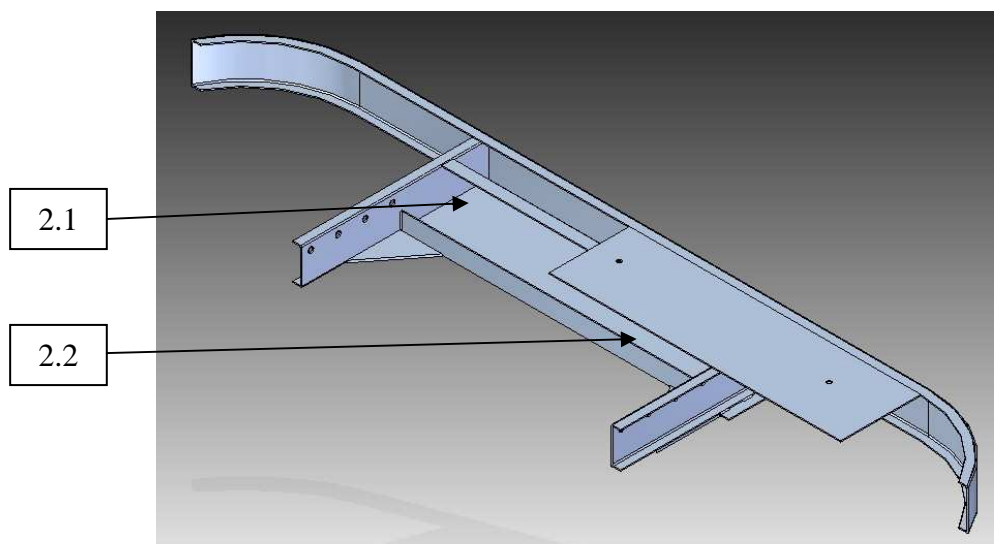Figure 1 Existing Bumper

2.1

2.2

Figure 2 Bumper Modified

Figure 2 shows two of the modifications I made to the bumper. Item 2.1 represents a 1.25'' angle steel bracket that will be welded in place. This is to help distribute the forces between the two brackets that bolt the bumper assembly to the frame of the truck. Item 2.2 is a steel plate that will be installed, this has two bolt holes that the base will bolt to.
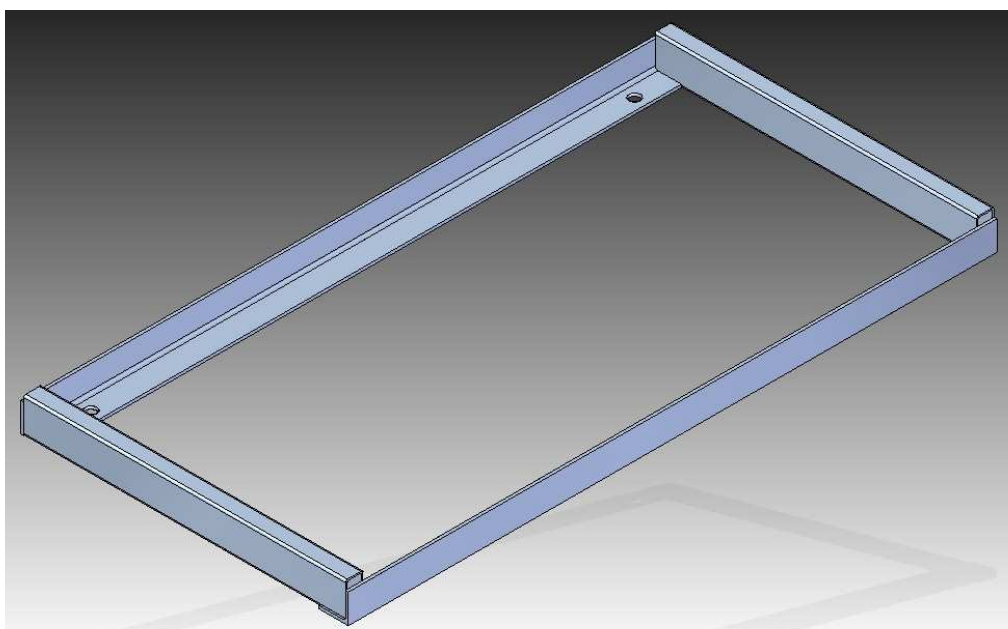

Figure 3 Base

Figure 3 is the base that will be bolted to the bumper with the two bolt holes pictured. The hydraulic cart will then we bolted to this base, design pending. This base is built out of 1.5'' box steel with 1.25'' angle steel welded on either end. This is the smallest box steel I could use while keeping the cart mounted level due to the design on the bottom of the cart. The base frame is as wide and long as the cart, 14'' by 27.75''. All of the weight of the cart will rest on the two box steel ends, the angle steel helps provide rigidity and fastening capabilities.
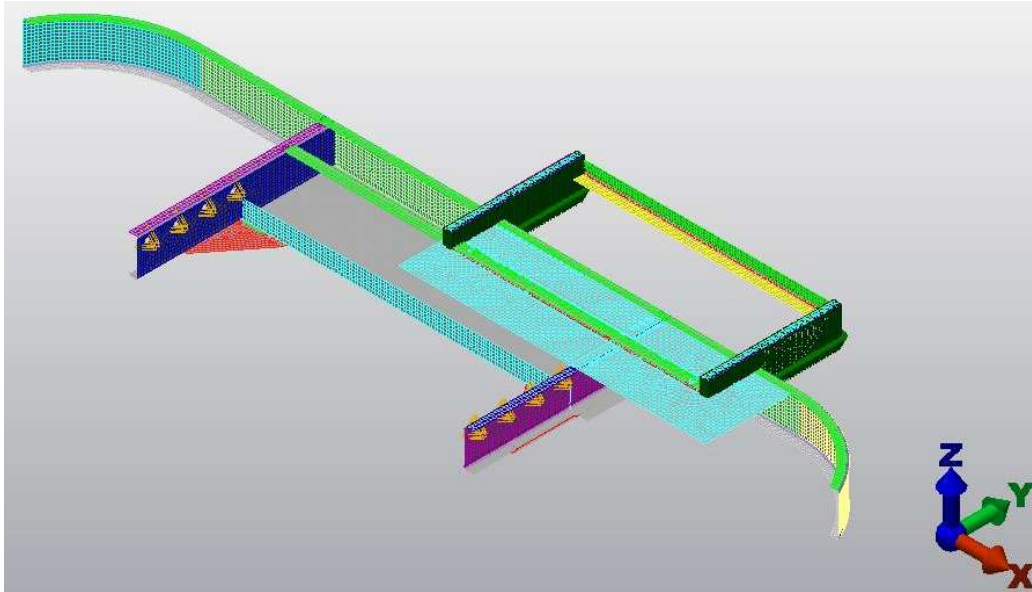
Figure 4 Original Algor Setup

Figure 4 demonstrates how this was simulated in Algor. The entire model was meshed using plate elements. I chose plate elements because all thicknesses were .125'' or smaller, and it would help increase run time. I could not find a way to cut this model down with symmetry because the load is not symmetric on the bumper.

I applied a downward force on the box steel equaling 400lbs, this would account for the 100lb cart, 150lb grill plus the weight of our 'fork' system used to move the grill away from the truck and also provide with a slight factor of safety. I then fully fixed the eight bolt holes that are used to bolt this assembly to the frame of the truck. I also made all of the parts to be ASTM A36 structural steel, which has minimum yield strength of 36,000psi and an ultimate tensile strength between 58,000 and 80,000psi.

Mesh Size (in)	Degrees of Freedom	Max. Aspect Ratio	σ_{MAX} ALGOR (PSI)	Percent Difference
0.5	51594	4.63	29,778	-
0.4	76866	3.97	36,881	21.31%
0.3	132366	8.05	44,045	17.70%
0.2	303642	14.01	53,265	18.95%

Table 1 Bumper One Results

Table 1 shows the results from applying a 400lb load to the base while attached to the bumper. I ran four different mesh sizes in hopes of showing convergence. However this design proved to be a little bit unstable with the stress starting out at about 30ksi and increasing to over 50ksi. The stress was mostly concentrated in the bracket that bolts the bumper to the truck. So I decided to change my design and try to help distribute those stresses to other parts of the bumper.
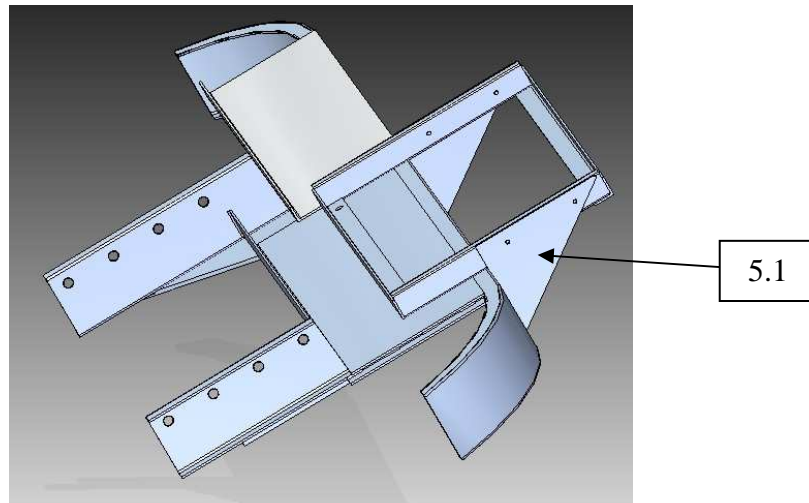
Figure 5 Modified Base

Figure 5 shows the changes I made to the base being effectively used in the bumper assembly. Item 5.1 is a triangular bracket I designed to bolt to the base assembly. It will have an interference interaction with the bumper; it can push against the bumper helping distribute some of the stresses seen from the 400lb force acting on the base. The same exact constraints and conditions were used as seen from Figure 4.
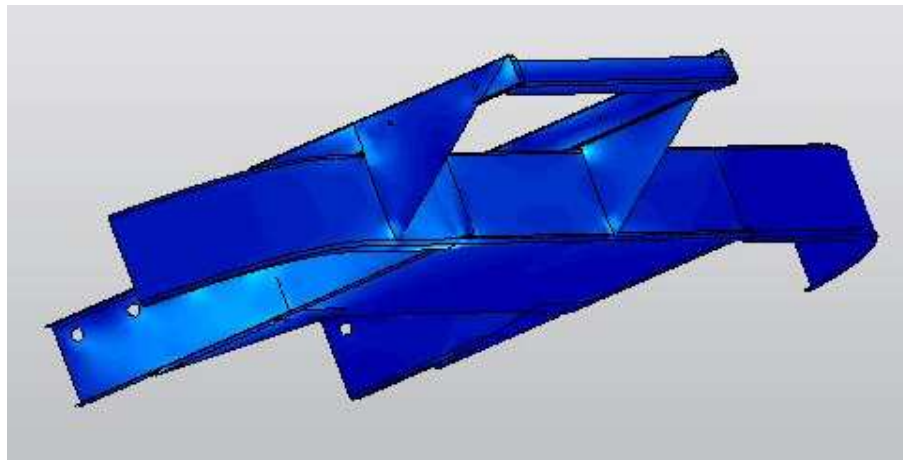

Figure 6 Stresses on Original Bumper

Figure 6 shows how the stress is no longer focused on the mounting bracket, but can be seen in the triangle brackets as well as the bottom portion of the bumper. However the maximum stress was still seen on the mounting bracket.

Mesh Size (in)	Degrees of Freedom	Max. Aspect Ratio	σ_MAX ALGOR (PSI)	Percent Difference
0.5	62202	61.04	20,314	-
0.4	Error Out		20,314	0.00%
0.3	151974	25.15	33,429	48.81%
0.2	338742	14.04	28,482	15.98%

Table 2 Bumper Two Results

We can see that from Table 2, the triangular brackets helped significantly in spreading and reducing the stress seen in the bumper assembly. However the results increase and decrease over the course of the four meshes, with the 0.4 inch mesh not completing due to an error. The triangular brackets seemed to be the solution to the problem, but this would decrease from the simplicity I was hoping to achieve. The bumper in real life has two curves not pictured, so the triangle brackets would need to be manufactured with the same curvature.

The plan was to move forward with the design in Figure 5, by coming up with some sort of bracket to help distribute the stress. On March 3, 2010 Aaron, Colin, and myself went out to Patricia's to do some repairs to her existing bumper and so I could get more accurate measurements to construct the brackets I needed. We discovered that the entire bumper assembly seen in Figure 1 is actually aluminum. This was a huge red flag for us because my design required us to weld a new bracket to the bumper; we also needed to fix many existing welds that had been broken. Her existing bumper was in such bad shape, and it is very hard to weld and repair aluminum that we decided to scrap her bumper and design a new one.
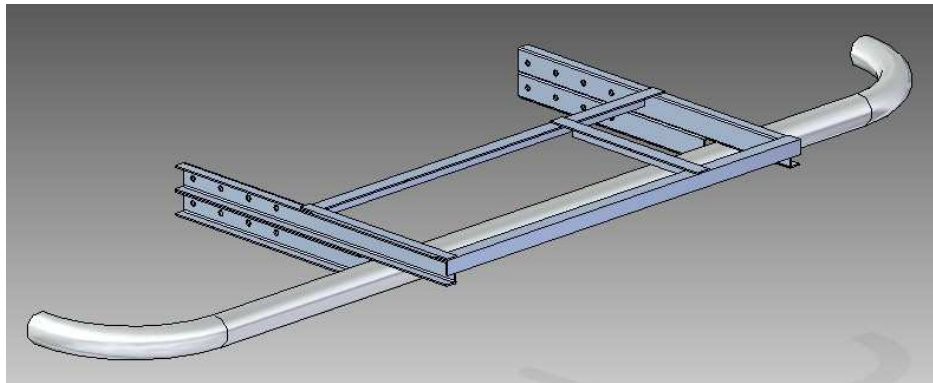

Figure 7 New Bumper

Figure 7 is the current design we are thinking of using for her bumper. By designing a new bumper I am able to mount the cart in a better spot. Here I can mount the cart between the two c-channel supports that will bolt to the frame of the vehicle. I can also do away with the base assembly that I had to create to affix the cart to the bumper.
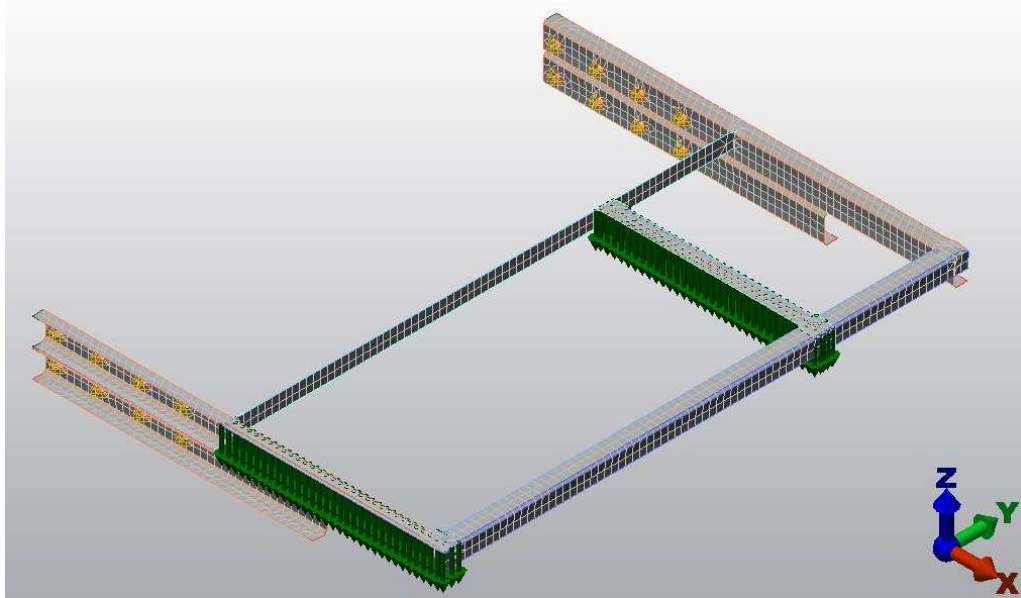
Figure 8 New Algor Setup

As seen in Figure 8, the weight of the cart will now be resting directly above one c-channel bracket and on a piece of angle steel. All of the members in Figure 8 will be made out of steel, and there will now be sixteen bolts holding this to the frame of the truck instead of eight.
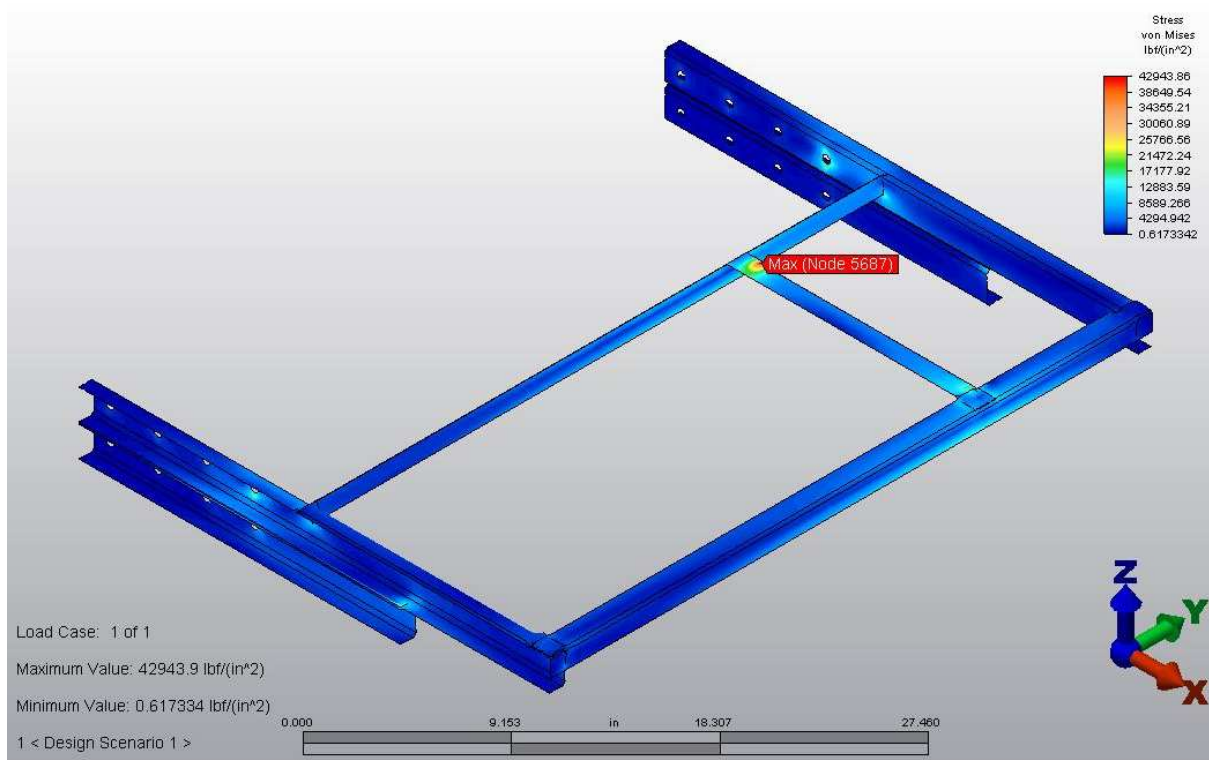

Figure 9 Stresses on New Bumper

Figure 9 shows how the new bumper reacts under the same 400lb load. The stresses are distributed between the two mounting brackets which is good. The maximum stress is still over the yield strength of steel, reaching as high as 49ksi as seen in Table 3 below. The maximum stress is focused on the inside corner of the angle steel, seen in Figure 9, which is acting as a stress concentration factor. This particular corner is the result of cutting part of the angle steel so that it will fit together correctly to be welded in place.

Mesh Size (in)	Degrees of Freedom	Max. Aspect Ratio	σ_{MAX} ALGOR (PSI)	Percent Difference
0.5	18216	7.6	36,423	-
0.4	25008	9.9	32,999	9.86%
0.3	36834	7.80	42,944	26.19%
0.2	96786	5.3	49,108	13.39%

Table 3 New Bumper Results

This study has shown me the importance of being able to spread the stress out among other members so as to not concentrate it all in one place. An effective way to do this is with various types of brackets. Since the discovery of her current bumper I have not had much time to redesign the cart attachment, which will look very similar to Figure 9. I also plan on putting a rounded surface in the cut corner of the angle steel to help reduce the stress concentration factor.

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3-9-10

<u>Parametric Study</u>

Introduction:

The purpose of the study is to minimize the weight of the design grill by applying a 100 lb

force to its handle and to confirm its durability. The results from the study will help minimize cost

for the project. Figure 1 shows a Solid Edge image of the complete grill. Steel is the best material

for the grill because its withstanding of hot temperatures, easy maintenance, and durability. The

study should confirm what thickness would be best for the grill.
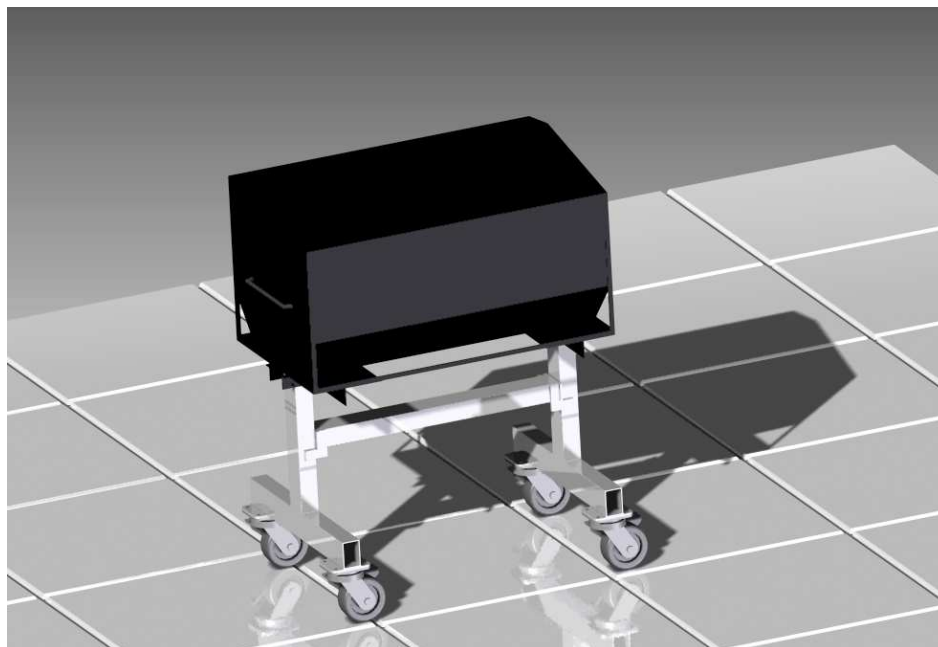
Figure 1: Image of the Design Grill in Solid Edge

Methods:

A model of the grill base was designed first in Solid Edge using the new Synchronous

Technology. Figure 2 shows the full assembly of the grill base in Solid Edge. The only side that

would need to be analyzed is the side with the handle, therefore other material on the grill base can

be negated out. There will not be any stress in any location of the grill base except for the side with

the handle. To cut time with the FEA, the rest of the material can be removed as shown in Figure 3

and 4. Figure 3 shows the grill frame at a thickness of 1/8 inch, which is going to be used for the

first analysis study. Figure 4 shows the grill frame at a thickness of 1/16 inch, which is going to be

the second analysis study. After the two FEA's are completed, the thickness that is best for the

project can be determined. An engineering draft was done for each frame to see the dimensions

located at the end of the report. It was easy to modify the part in Solid Edge when needed.

Symmetry could have been applied to the grill frame, however it would be better to see where the

stress was acting on the whole frame, due to the customer pushing or pulling on that side. The grill

frame was then imported into Algor to get a stress analysis. A mesh of 0.5 inch was the starting

mesh for the grill frame. It was meshed down until the stress started converging.
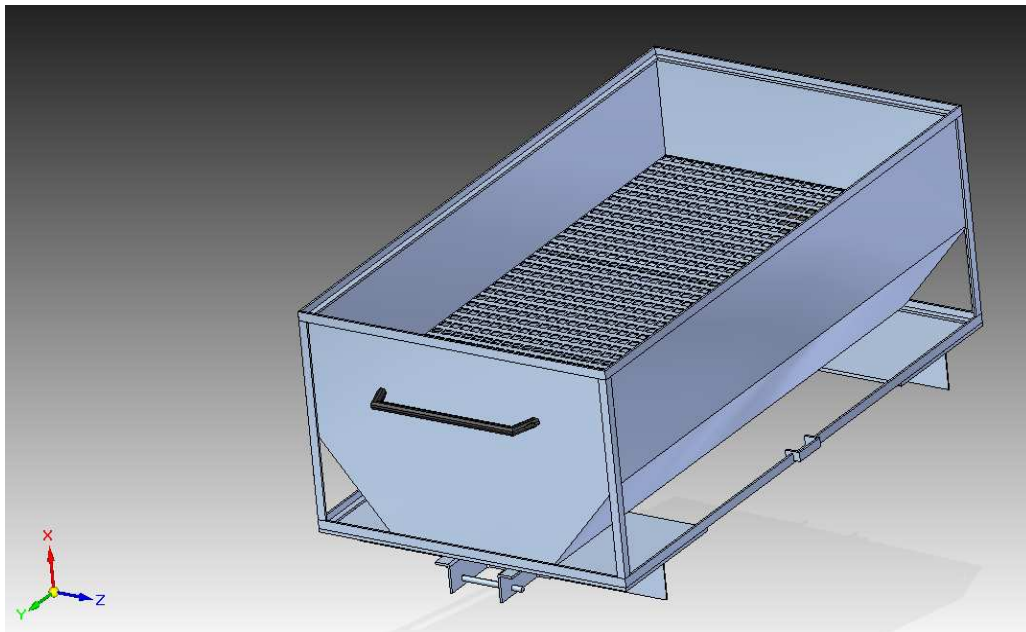
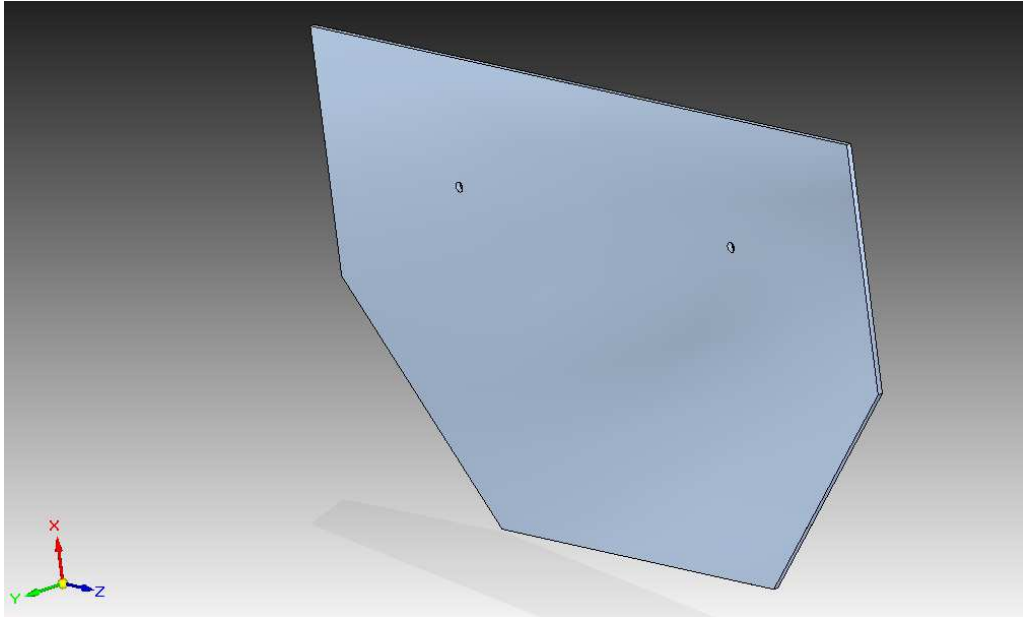
Figure 2: Grill Base in Solid Edge

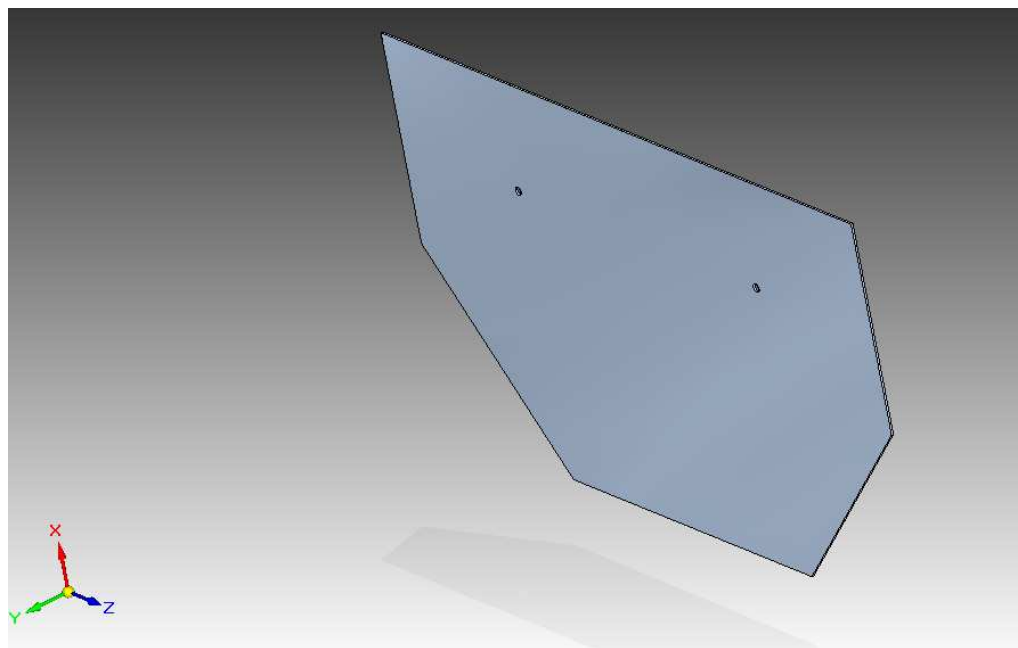**Figure 3:** Grill Frame at 1/8 inch thickness in Solid Edge

Figure 4: Grill Frame at 1/16 inch thickness in Solid Edge

Results:

The grill frames were imported into Algor to get a stress analysis report on them. Figure 5 gives an image of the material properties of the AISI 1018 Steel for the grill frame. The team decided this would be the best material for the frame because of its durability and low cost. This

decision was made after looking over the NSF standards for cooking equipment. Table 1 and 2

show more properties for the grill frame at 1/8 and 1/16 inch thickness including the weight,

volume, center of gravity, and mass moment of inertia.

Table 1: Material properties for AISI 1005 Steel found in Algor

Material Properties	
Material Specified	AISI 1018 Steel, cold drawn
Modulus of Elasticity (lbf/in^2)	29,733,000
Poisson's Ratio	0.29

Table 2: Weight Properties found in Algor for 1/8 and 1/16 inch thickness for Grill Frame

Weight	
1/8 Thickness	7.06 lbf
1/16 Thickness	3.39 lbf

Figures 5 and 6 show where the constraints were placed on the grill frame. The top, sides,

and bottom of the grill frame were fully constrained due to the angle iron that will be welded to the

sides. The grill frame will not be able to move in any direction. The 100 lb force was distributed

equally between the two holes where the handle will be bolted by selecting vertices around the

holes.
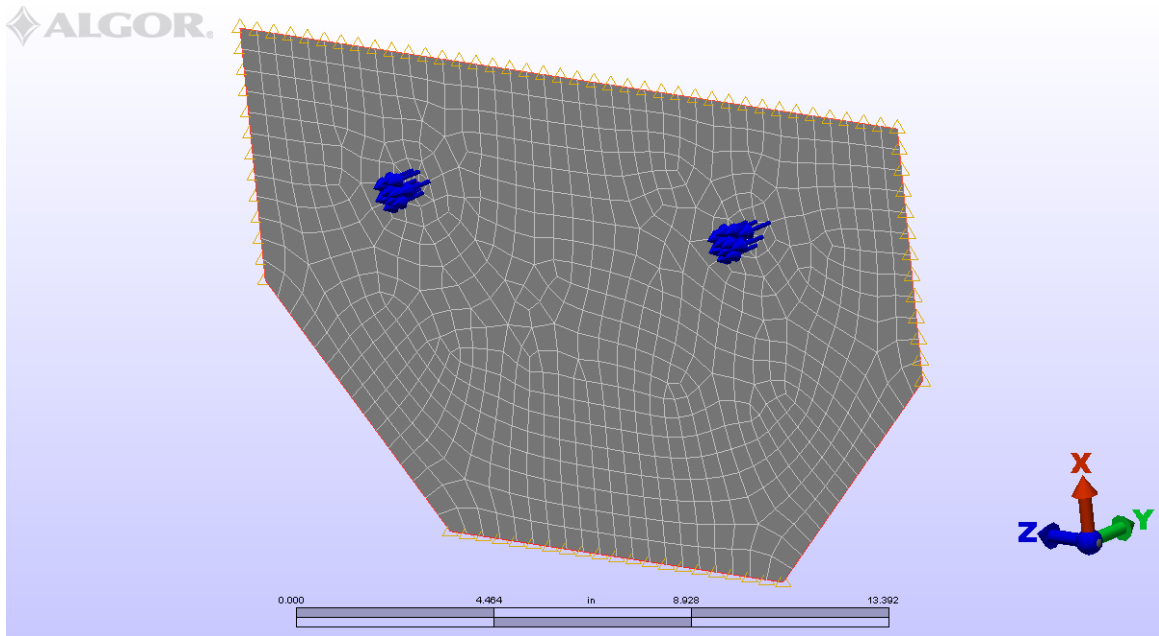
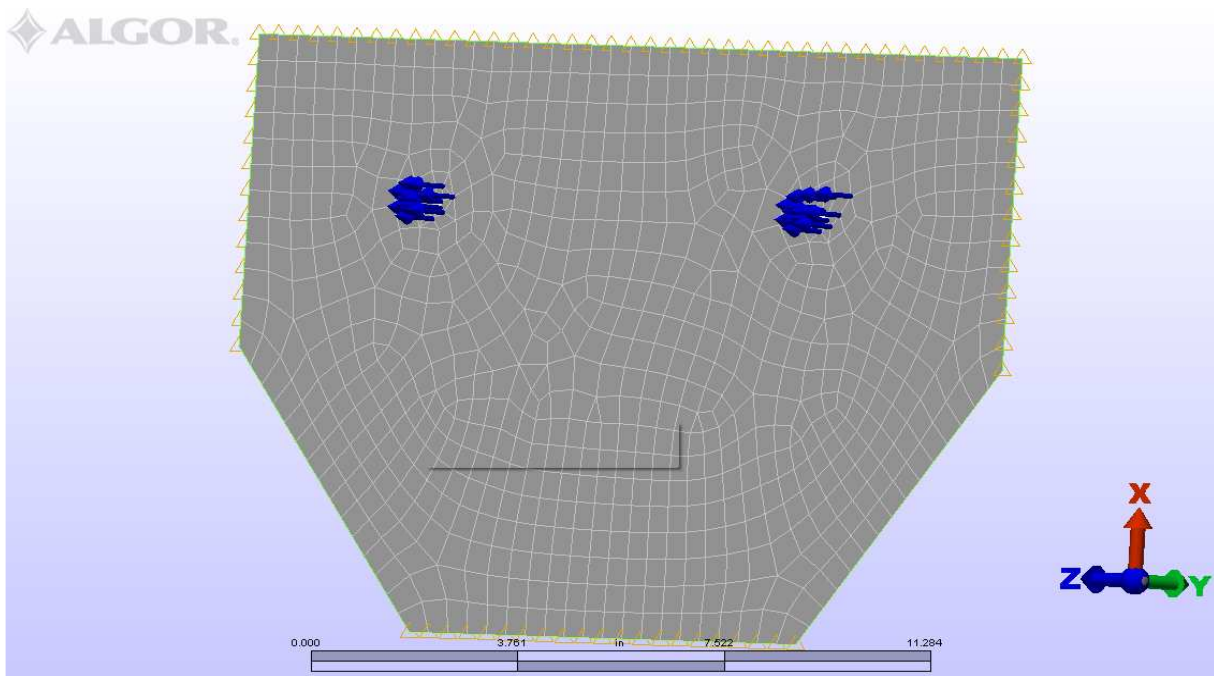**Figure 5:** Grill Frame of 1/8 inch constrained in Algor

Figure 6: Grill Frame of 1/16 inch constrained in Algor

The frame was analyzed until the von Mises stress converged in the test for both thicknesses. The results for each mesh of 1/8 and 1/16 inch thickness are shown in Table 3 and 4. You can see it starts to converge at the 0.2 inch mesh because the percent difference was 0.15 % for 1/8 inch thickness and 0.23 % for 1/16 inch thickness. Figure 7 and 8 show a graph of the von

Mises Stress verses the degrees of freedom. You can see on the graph that it does converge at the 0.2 inch mesh. The graph just verifies the results and tests, meaning that both thicknesses would support the grill base.

Table 3: Results found in Algor for 1/8 inch thickness

Mesh (inch)	Number of Surface Elements	Model Degrees of Freedom	Max. Aspect Ratio	σ_{max} (lbf/in^2)	Percent Difference
0.5	754	4302	1.55	3825	
0.4	1108	6360	1.44	3907	2.12%
0.35	1498	8646	1.45	3985	1.98%
0.3	1963	11358	1.49	4008	0.58%
0.25	2782	16164	1.39	4025	0.42%
0.2	4365	25428	1.36	4031	0.15%

Table 4: Results found in Algor for 1/16 inch thickness

Mesh (inch)	Number of Surface Elements	Model Degrees of Freedom	Max. Aspect Ratio	σ_{max} (lbf/in^2)	Percent Difference
0.5	754	4302	1.50	16620	
0.4	1108	6360	1.44	16957	2.01%
0.35	1498	8646	1.45	17285	1.92%
0.3	1963	11358	1.49	17382	0.56%
0.25	2782	16164	1.41	17456	0.42%
0.2	4365	25428	1.36	17496	0.23%
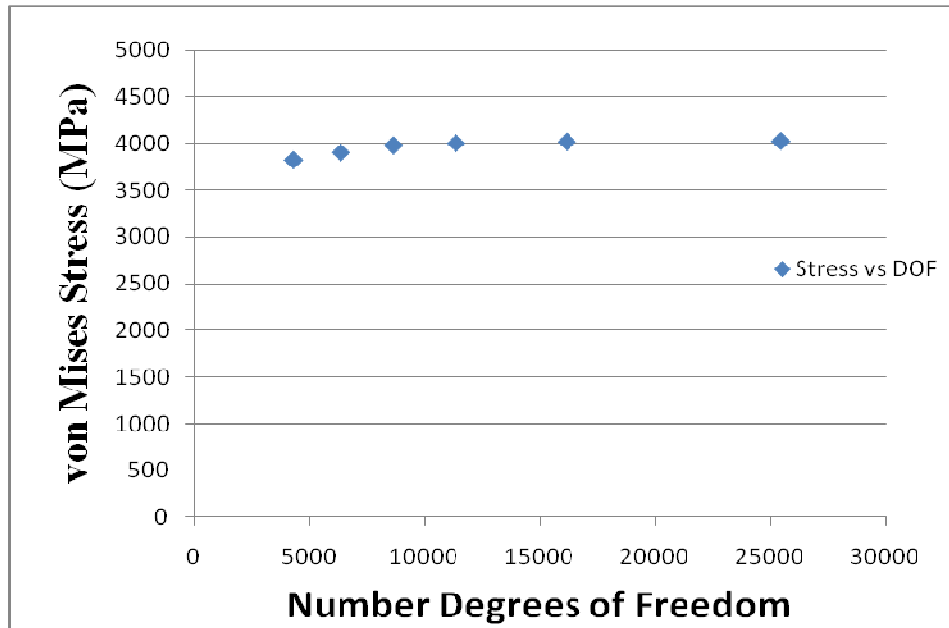
Figure 7: Stress verses the degrees of freedom graph for 1/8 inch thickness
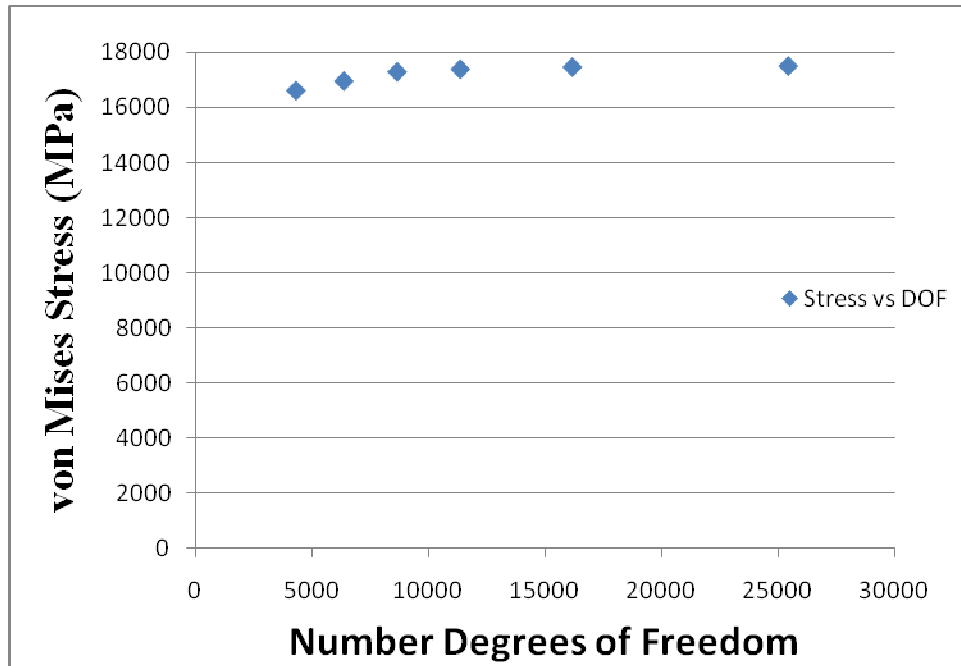
Figure 8: Stress verses the degrees of freedom graph for 1/16 inch thickness

Figure 9 shows the stresses that were acting on the grill frame. As seen in the figure, the maximum stresses were presented around the holes. Those forces were not correct at all so the elements around the holes were hidden to get more precise results. Figure 10 shows the stresses presented at the top of the frame, which was the assumption. Figure 11 shows bracket at a displacement of 50 %.
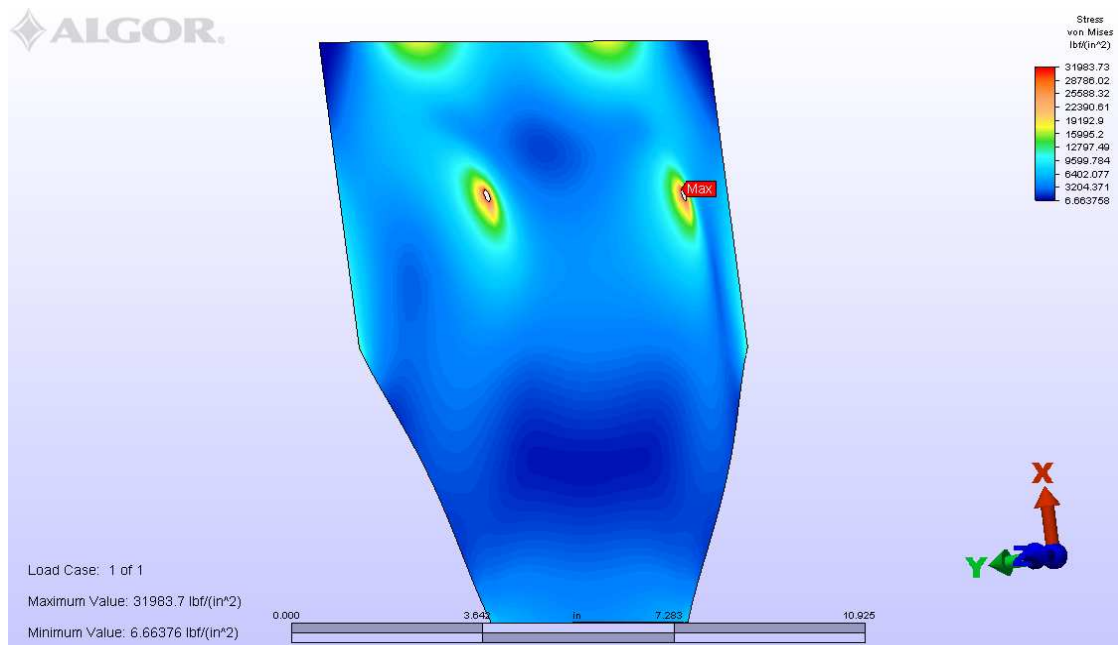
Figure 9: Stress analysis on the grill frame for the 1/16 inch thickness
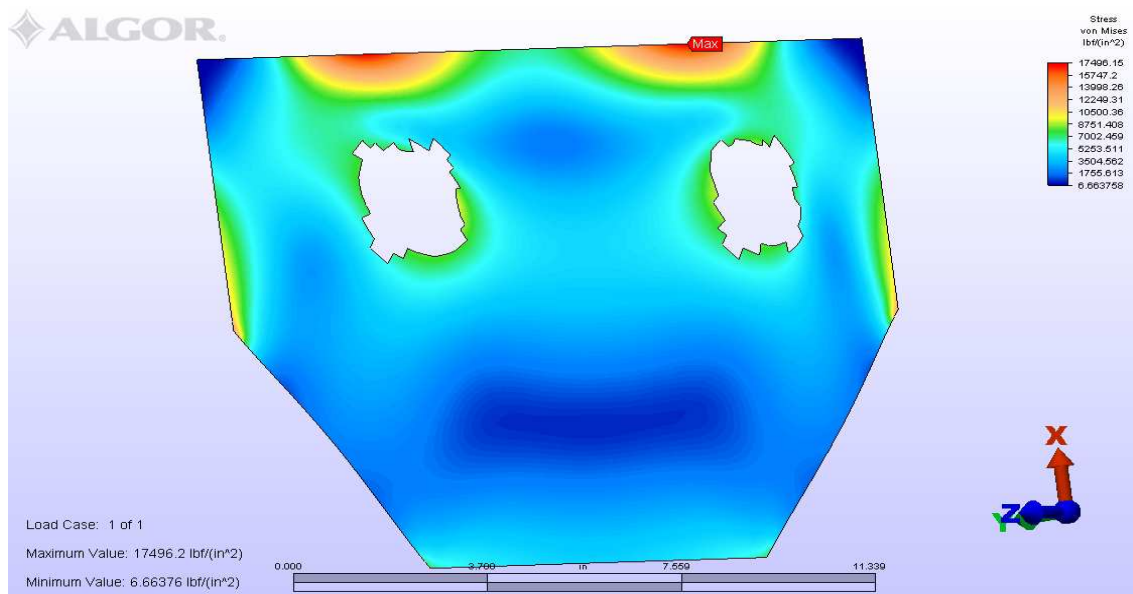
Figure 10: Stress verses the degrees of freedom graph for the 1/16 inch thickness
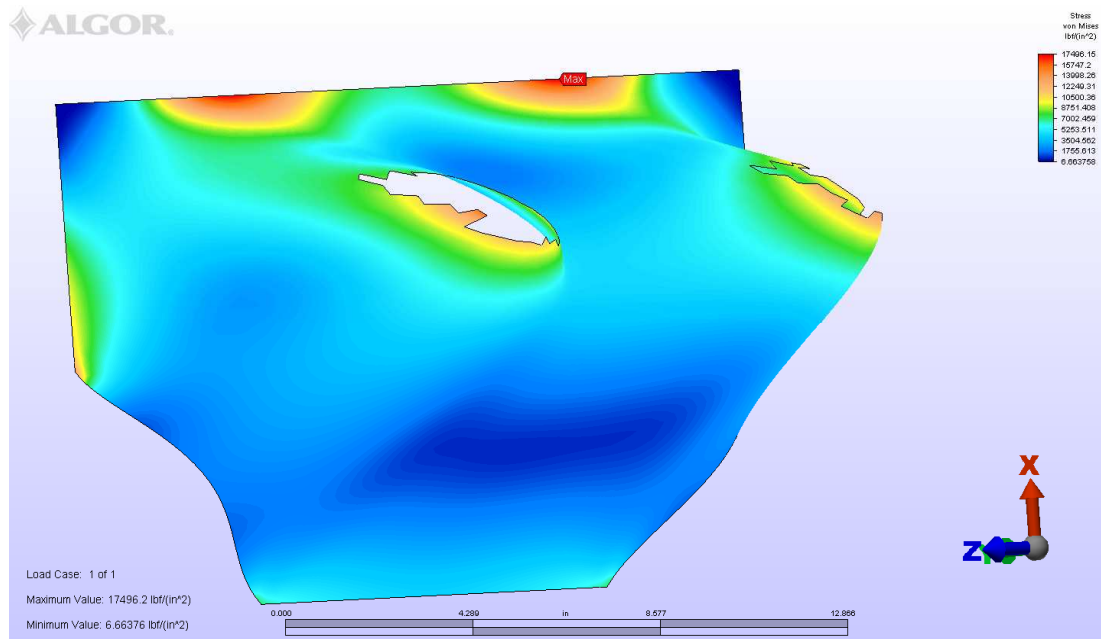
Figure 11: Displaced at 50 % in Algor for the 1/16 inch thickness

Conclusion:

After viewing the results, it was determined that either thickness would work for the grill base. Shown in Table 3 and 4, the grill frames for 1/8 and 1/16 inch did not exceed expectation of 351,283 psi, which is the yield strength for AISI 1018 Steel. The maximum stress for my bracket was 17496 psi. From these results, it can be concluded that the team can order and use a 1/16 inch thick grill base. By using the 1/16 inch thick grill base instead of the 1/8 inch, will cut much cost for the project.

ME 488 Experimental Procedures & Results

Winter Quarter 2010

Colin Harris, Daniel Shapiro, Aaron Shelly, Colton Shoemaker, and Shad Williams

3/17/2010

Three experiments were conducted to assist in the design of a portable grill system for Patricia Thomas. An experiment to observe the rate of cooling of a grill under operating conditions was used to determine the amount of time required to lower a charcoal grill's temperature from operating temperatures to a level low enough for safe handling without the use of protective gloves. The experiment was performed using a similar charcoal grill, type k thermocouples, and a digital handheld reader. Another experiment was conducted to determine the optimal lever arm length for use on a hydraulic lift cart under load. A total of 21 different scenarios were tested to observe the performance of the lift cart under different loads with three different lever arm lengths using a force transducer and an automated data collection system. The final experiment for the grill design was a test to determine the force required for a four caster system of the design's intended weight to be moved up various inclinations. From the temperature experiment it was determined that under the conditions tested it would require at least 143 minutes for a charcoal grill to reach a temperature less than 120 F. Based upon the observations in the lever arm experiment an optimal length was determined to be in the 18 24 inch range, providing a compromise between required force and stroke length, while requiring a maximum of only 26.61 pounds force to operate the lift. Finally, the slope experiment verified that grill's user should be able to move the grill at an incline of 8.63 with a pushing force of only 25.76 pounds.

Contents

Section 1: Introduction

Section 1.1 Overview

The experiments discussed in this report all relate to the Ohio University Russ College of Engineering and Technology's mechanical engineering senior design project for Team OU BBQ. Team OU BBQ is working to design and manufacture a truck mounted, mobile grill system for one Patricia Thomas. The grill system will need to be easily unloaded and moveable on and off the customer's mobile vending truck and be safe to handle in a timeframe typical to the customer's normal operations.

The experiments discussed herein were designed and performed to ensure that the customer's needs were satisfied. The customer's situation required that the grill system be operable by a single individual, have a larger cooking capacity than the user's current setup, and that the system would not require an undue amount of force to run during any of its operation modes.

All three of the experiments performed were designed to verify that individual components of the proposed design will be able to operate in the desired ranges. The first experiment will provide a representative range for the time required to lower a charcoal grill's temperature from operating temperatures to a level low enough for safe handling without the use of protective gloves. The second experiment will allow for the optimization of the lever arm length to be used on the proposed lift mechanism and show if the force required is in an acceptable range for an individual to exert. The final experiment will be used to determine if the system will be able to be moved around by a single individual under different inclinations.

In an ideal system, the behavior of the rate of cooling could be predicted exactly using Newton's law of cooling. Newton's Law of Cooling states that the rate of change of the temperature of an object is proportional to the difference between its own temperature and the ambient temperature. [4] Based on the assertion made by Newton's law, Equation 1 can be derived.

$$\frac{dT}{dt} = -k(T - T_0) \tag{1.}$$

Where $\frac{dT}{dt}$ is the first order differential of the temperature with respect to time, which represents the time rate of change of the temperature. K is a cooling constant, T is the temperature at the given time, and T_0 is the initial temperature.

Using this equation, one could accurately predict the rate at which an object would lose its thermal energy to the environment, assuming no other variables like wind or changing ambient temperatures came in to play.

One of the largest features of the grill lift system is the manually actuated hydraulic lift table that raises the grill on and off customer's vehicle. Since the large portion of the hydraulic lift system was sourced from off the shelf components one of the few remaining variables left to design is the length of the lever arm used to operate the hydraulic cylinder.

A lever is one of the most basic simple machines. The operation of a lever arm is generally defined with the relationship shown in Equation 2.

$$F_1 D_1 = F_2 D_2 \tag{2.}$$

Where is F_1 the force on one side of the fulcrum, D_1 is the distance of the load from the fulcrum, and F_2, and D_2 are the same respective quantities for the other side lever.

Since there is no machine that can increase both the magnitude and the distance of a force, when a machine produces an increase in output force, there is always a proportional decrease in the distance moved. In the case of the desired system's lever arm, the distance the arm must travel will increase as the required user input force decreases.

Because the customer's operational venue will not always be a level surface, it is important that the grill design be able to operate under a reasonable degree of inclination. For the design process a 'reasonable degree of inclination' is defined as the maximum recommended wheelchair ramp inclination of six degrees. To calculate the force required to move an object on a non-level surface the largest theoretical magnitude should arise when the object on the slope must overcome both the force due to gravity and the frictional force.

Section 1.2: Temperature Literature Review

Ohio University's Mechanical Engineering 388 Data Analysis course uses a few tests using similar equipment to measure temperature. In its temperature lab, the OU ME 388 experiment uses a couple of temperature measuring techniques including thermistors, mercury-in-glass thermometers, and type K thermocouples to measure the temperature and observe the cooling down of water from 75°C down to 40 °C. The OU experiment explains and shows that type K thermocouples are more than acceptable for temperature measurement across a wide range of different temperature levels, and that the rate of cooling is expected to happen in a nonlinear fashion.

The OU ME 388 course also has an experiment that utilizes handheld digital readers for type k thermocouples similar to the one used in the temperature experiment. In the OU experiment the input and output temperatures of a Stirling refrigeration unit are read off of the digital handheld units. From the Stirling refrigeration experiment the use of a single reader unit is shown to be accurate enough to observe the temperature difference between the acceptor and rejector heads of a Global Cooling M100B refrigeration unit and its variations as different heat loads are applied.

Section 1.3: Lever and Slope Force Literature Review

As both the lever and slope experiments deal primarily with the recording of forces required to move or operate an object under different loads, their testing is done in a similar fashion. Ohio University's Mechanical Engineering 388 Data Analysis course runs a wind tunnel experiment where the amount of lift and drag force generated from a NACA airfoil is measured versus the angle of attack in an airstream. In the experiment a similar, although smaller, force transducer is used to read the airfoil force as the angle of attack is varied. The procedure calls for the calibration of the load cell before testing to ensure precise results.

Section 2: Experimental Apparatus and Procedure

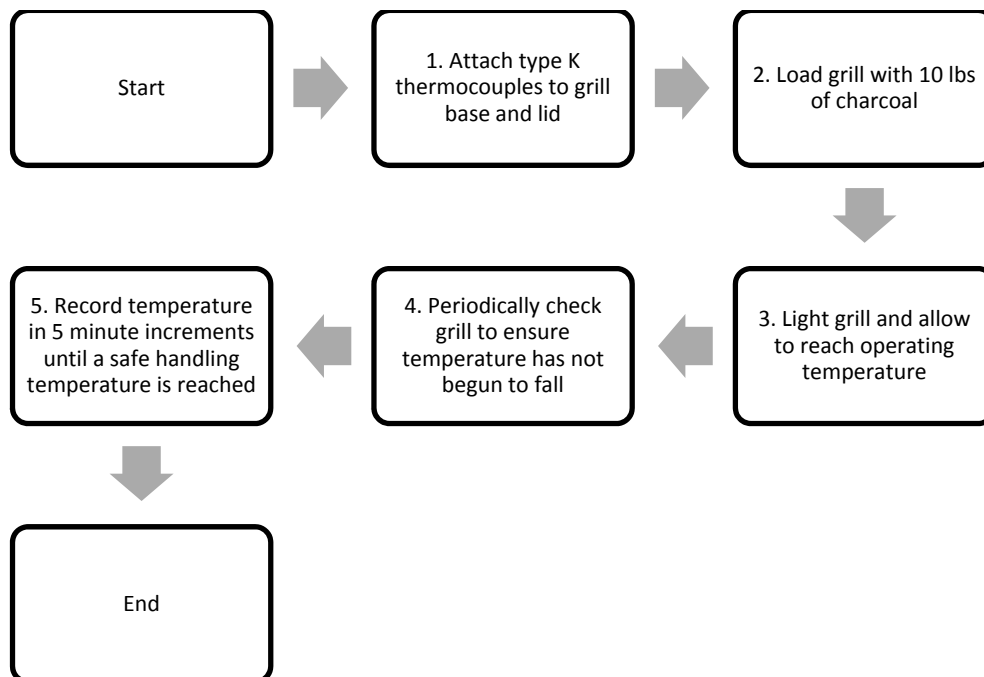**Section 2.1 Grill Temperature Apparatus and Procedure**

Figure 1: Flowchart of Experiment Procedures

For the measurement of the cooling rate of a charcoal grill under real world conditions a basic measurement and testing setup was used. The equipment used in the experiment was a large steel construction charcoal grill of similar size range to the proposed grill design, two type k thermocouples, a handheld Fluke digital thermocouple reading unit, ten pounds charcoal, and high temperature duct tape. For the experiment the two thermocouples were attached to the exterior of the grill on the lid and base using the high temperature duct tape as shown in the schematic of Figure 2, and the actual experiment photograph in Figure 3.
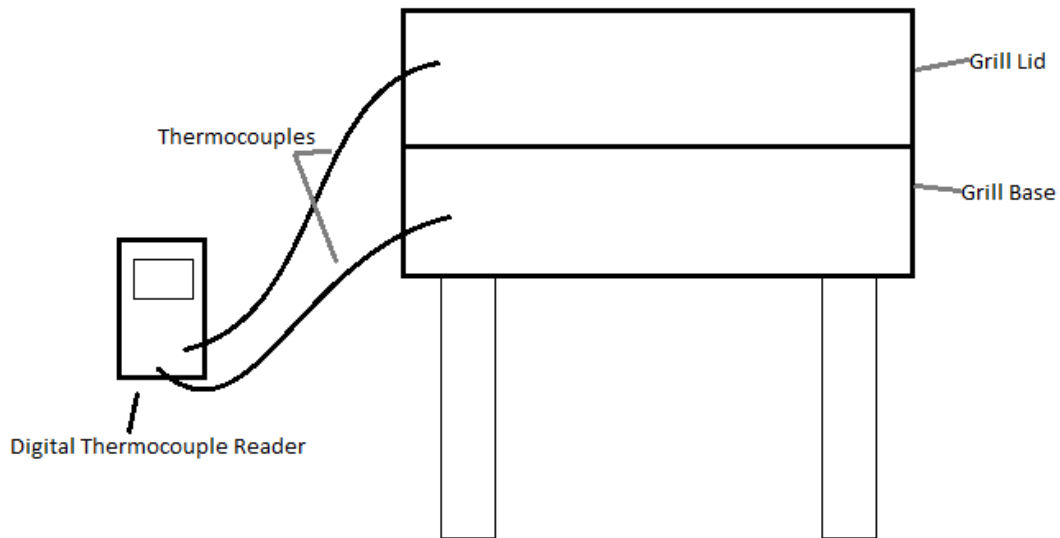

Figure 2: Schematic of Basic Test Configuration

Figure 3: Photograph of Experimental Setup

To simulate actual operating temperatures the grill was loaded with ten pounds of charcoal, a recommended amount for the sized grill used, and lit. The temperature was checked every few minutes until it reached a maximum. Once the grill began to cool down the lid was shut and temperature readings for both the base and the lid were recorded every five minutes until the unit reached a temperature low enough to be safely handled. The temperature data was then plotted versus time to see if it exhibited a predictable behavior.

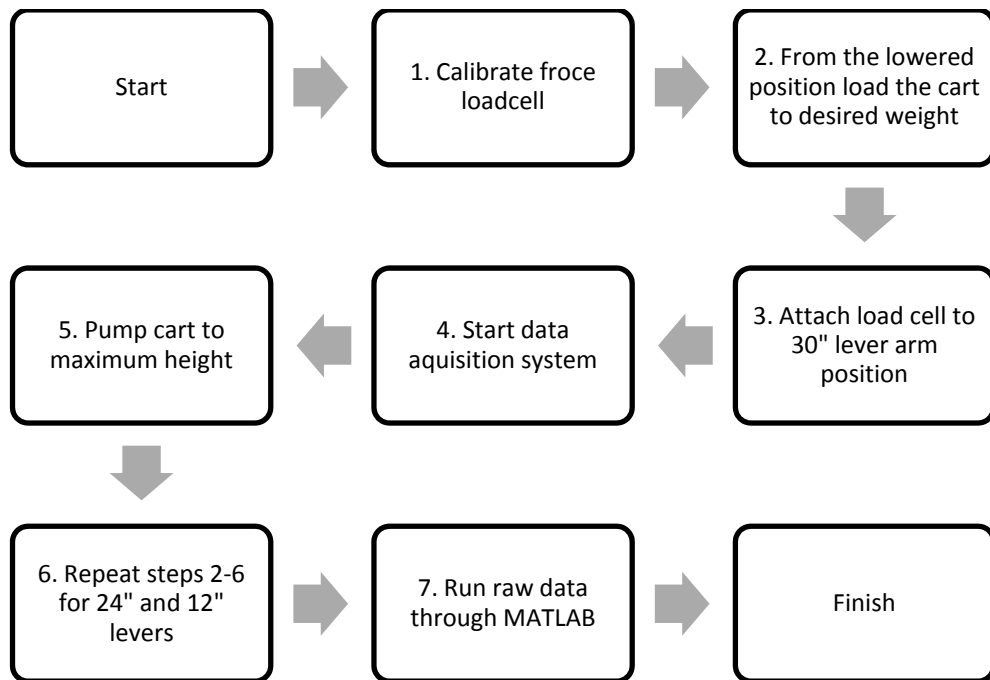**Section 2.2 Lever Force Experimental Apparatus and Procedure:**

Figure 4: Flowchart of Experiment Procedures

For the measurement of the force required to operate the intended lift mechanism, a series of tests were conducted using different lever arm lengths and loads. To perform this experiment, a Northern Industries 500 pound rated lift cart as seen in Figure 5, a National Instruments automated data collection system and computer software, different lever arms at lengths of 18, 24, and 36 inches, an Omega LC101-25 load cell/force transducer, and a container that can hold at least 27 gallons of water are required. An image of the test setup can be seen in Figure 6. For this experiment, the loads tested were zero, 50, 100, 150, 200, and 250 pounds. The weights used were various volumes of water held in an empty beverage cooler.

Figure 5: Northern Industries 500lb Lift Cart

Figure 6: Experiment Cart Setup

In order to verify that the data collected from the load cell was precise, a calibration was performed. Data

was first collected from the load cell with no load applied. This data was averaged in order to produce the

zero offset voltage. A precisely-known weight of 6.85 pounds was then applied to the load cell. The zero

offset voltage was subtracted from every value in the calibration weight data set and then averaged to

determine the voltage response of the load cell for a given weight. The zero offset voltage was found to be

4.117 mV. The load cell's output of zero mV at zero load and 4.117 mV at 6.85 pounds gave a more precise load curve than the one supplied with the load cell (Note: due to time and resource restrictions, a third calibration curve point was not recorded. Ideally, a third point would have been recorded in order to obtain a more precise load curve).

Using the data collection system and the force transducer, the force required to operate the lift cart at each of the weights and different lever arm lengths was recorded. In each test the cart was started from a completely lowered state and raised to the maximum operating height. The number of pumps required to operate the lift was counted and compared to the number of peeks in the force transducer data.

In order to obtain any useful results from the collected data, a MATLAB program was written to perform a running average of the data. The load cell voltage output was exported from the data acquisition software as a text file and then given a .dat file extension. The MATLAB .m file, readData (included in the appendix, courtesy of John Willis), extracts the numerical data from the .dat file and puts it into a matrix that can then be used in other MATLAB operations.

After calibrating the load cell, experimental data was recorded and saved as .dat files. The MATLAB program, forceCalc (included in the appendix), takes the matrix output from the readData program and performs a running average of the data via a "for" loop. The loop takes a certain number of values, k, from the data matrix, averages them, and stores the averaged value in a new matrix. The k value can be varied to average more or fewer values. The more values averaged the smoother the data becomes, but it also begins to reduce the peak values as seen in Figure 7. If too few values are averaged, noise remains in the output matrix as seen in Figure 8. The k value was varied to find a point where the data noise was just eliminated in order to find the closest approximation of the true value (presented in Figure 9). The averaged output voltages were input to the load correlation curve and a graph of the applied forces was plotted. In the case of the lever force experiment, this process yielded plots that clearly depict the peak forces associate with each lever push.
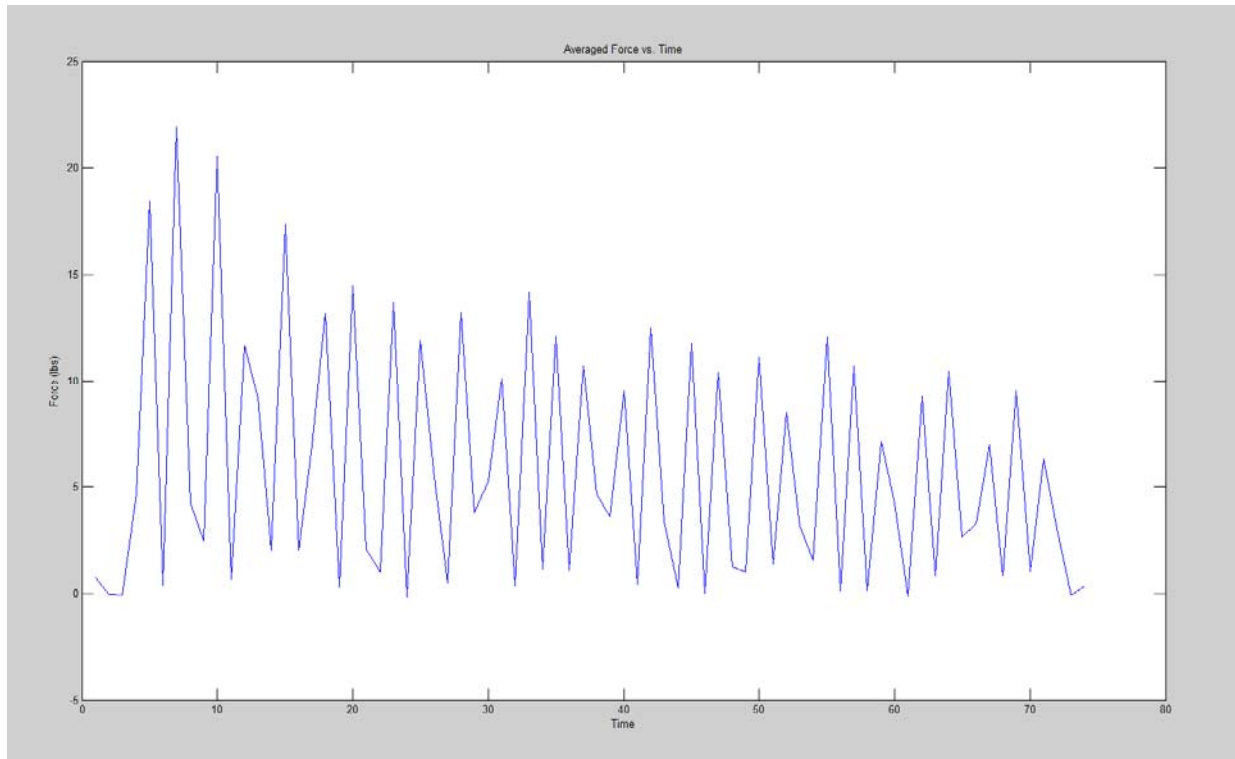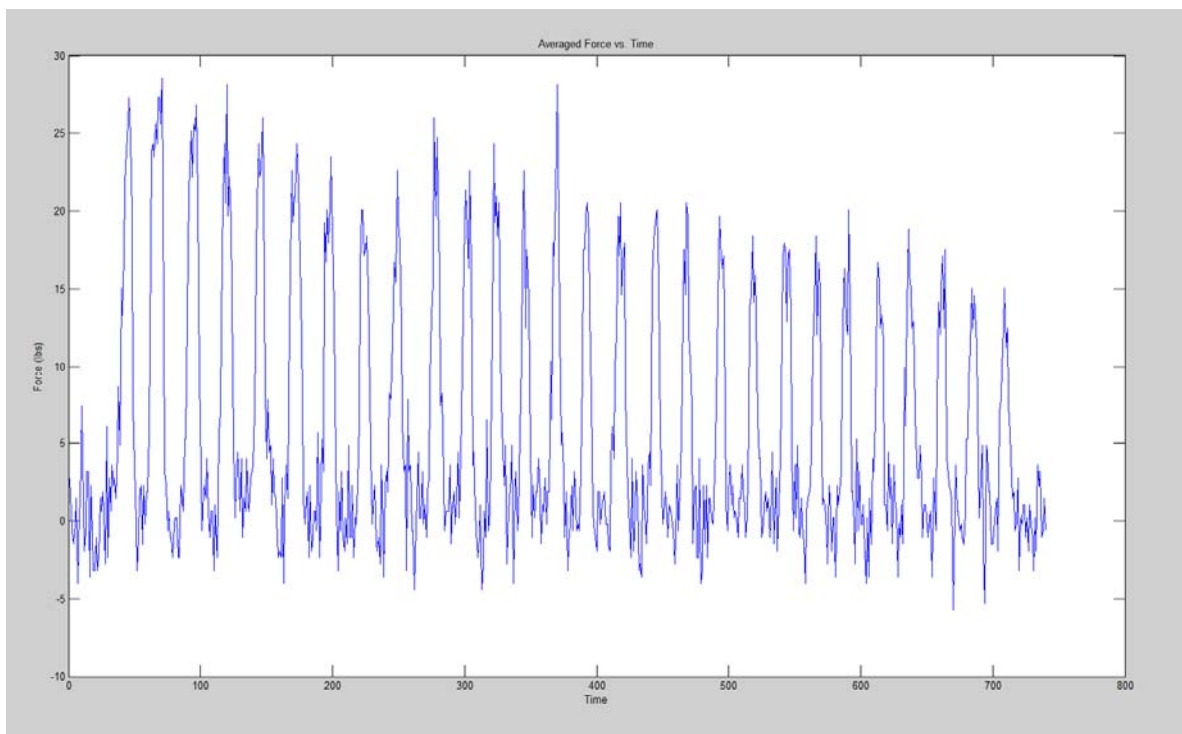
Figure 7: Averaged Lever Force Data, k=100
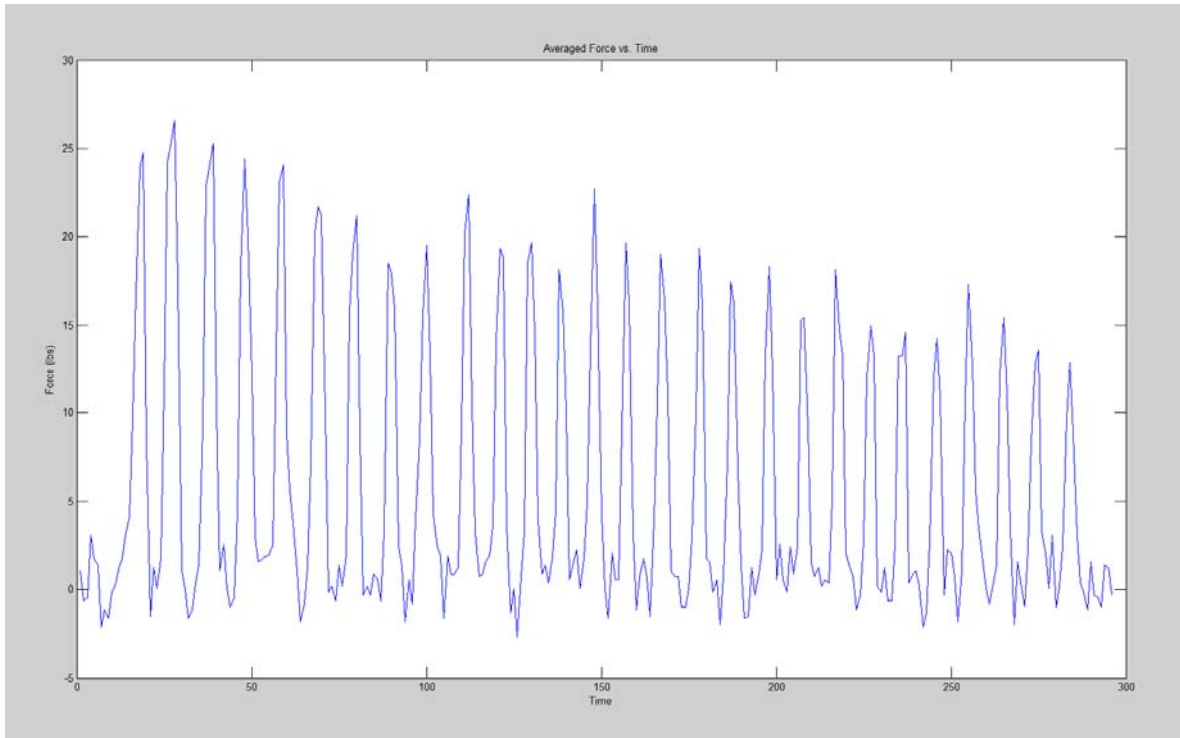

Figure 8: Averaged Lever Force Data, k=10

11

Figure 9: Averaged Lever Force Data, k=25

Section 2.3 Slope Lab Experimental Procedure and Apparatus:
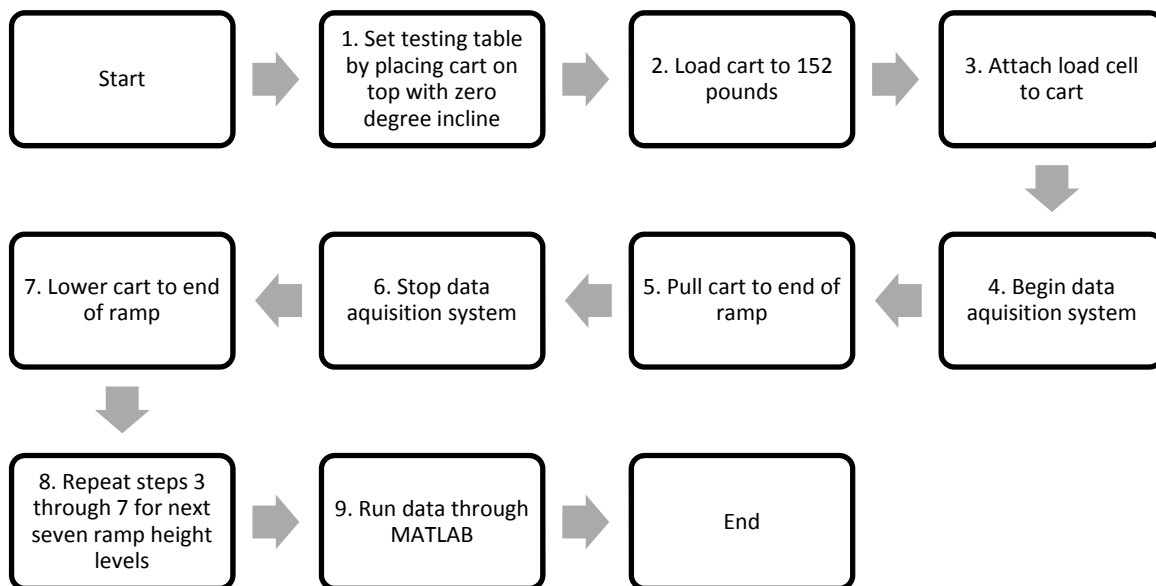

Figure 10: Flowchart of Experiment Procedures

For the measurement of the force required to move a loaded four caster system up a slope and determine the coefficient of friction, a series of tests were performed at different inclinations. To perform this experiment, a Northern Industries 500 pound rated lift cart, a National Instruments automated data collection system and computer software, a variable slope ramp, an Omega LC101-25 load cell/force transducer, and weight to load the cart to at least 150 pounds are required.

Starting from the 0° inclination, the setup was assembled as shown in Figure 11. The load cell was attached to both the cart and a pull handle. Care was taken to ensure the handle stayed parallel to the inclined surface. At the beginning of each trial, the cart was held still for a period of approximately ten seconds to observe the static equilibrium force. After ten seconds, the experimental operator began pulling the cart until it reached the top of the ramp. The cart was carefully lowered back down the ramp and the platform was raised up one increment. The process was repeated for eight trials until the maximum design inclination (6°) was surpassed.

Figure 11: Photograph of Test Setup

13

The MATLAB code used for the lever force lab was used to refine the data collected during the experiment. After refining the data, the maximum amount of force required during each test was plotted versus the angle of inclination. The angle of inclination for the test platform was determined using the hand calculations found in Appendix A.

Section 3: Experimental Results and Discussion

Section 3.1: Temperature Experimental Results and Discussion

The data collected during the temperature lab is presented in Figure 12 below. The base temperature is represented in red and was consistently higher than the lid temperature. The lid temperature is shown in blue and was the first portion of the grill to cool to a safe-to-handle temperature.
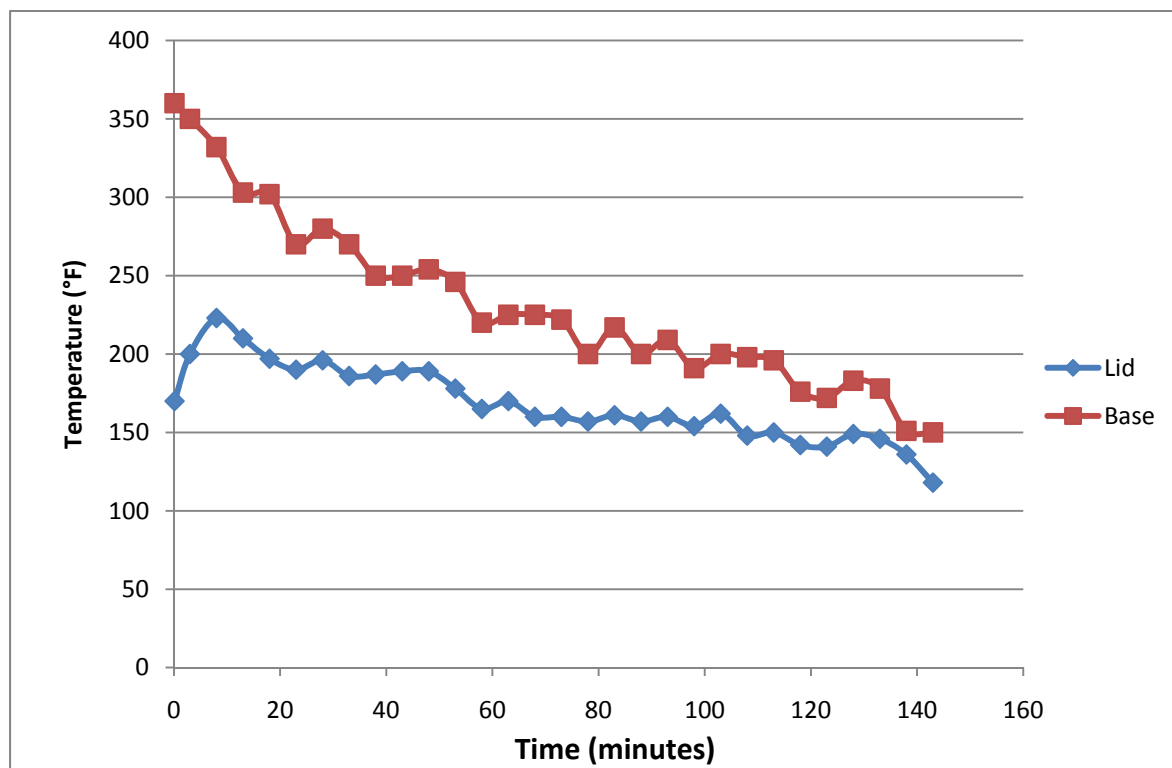

Figure 12: Temperature Vs Time Plot

Section 3.2: Lever Force Experimental Results and Discussion

The maximum force required to depress the lever in each of the trials is presented in Table 1 below.

From Equation 2, it was expected that the force required would be greater the shorter the lever arm is and

the data showed this consistently. The linear nature of the force values can be seen in Figure 13. Also in

Figure 13, it can also be observed that the maximum force required for each trial increased in a fairly

linear manner as the load was increased.

Table 1: Summary of Max Force Required to Operate Lift Cart

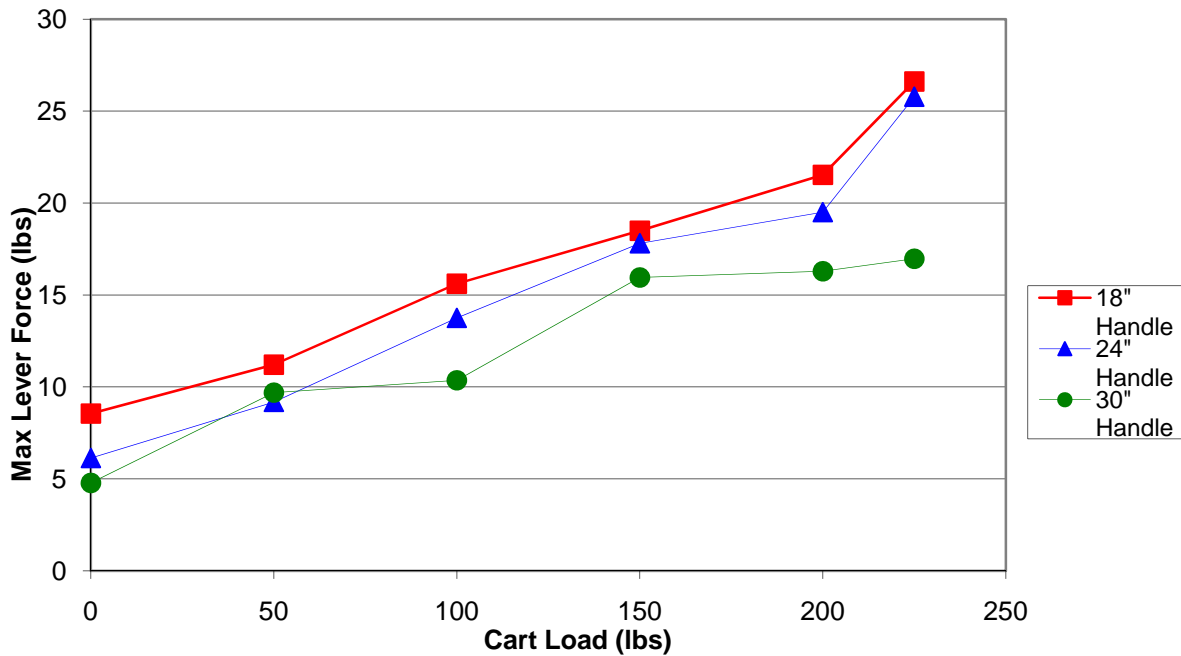| Weight	18" Lever Force	24" Lever Force	36" Lever Force
0	8.55	6.13	4.78
50	11.21	9.18	9.69
100	15.61	13.75	10.36
150	18.49	17.81	15.95
200	21.53	19.5	16.29
225	26.61	25.78	16.97

Figure 13: Maximum Lever Force Vs Cart Load

15

Section 3.3: Slope Force Experimental Results and Discussion

The maximum force recorded for each of the eight trials are presented in Table 2 below. As expected the

force followed a fairly linear trend, increasing with angle of inclination. Results ranged from 12.39

pounds at 0° to 25.76 pounds at 8.63°. The linear nature of the force/angle relationship may be seen in

Figure 14.

Table 2: Results Summary of Slope Lab

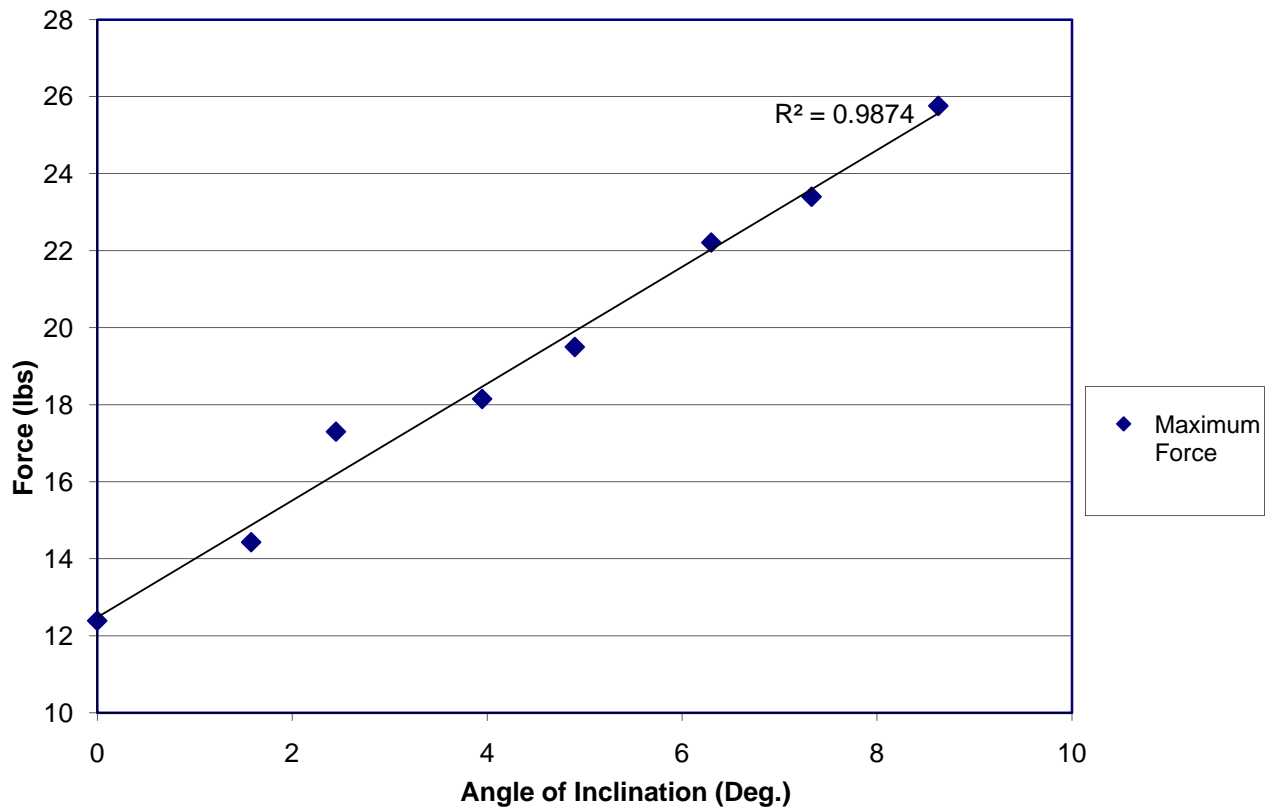| Angle of Inclination	Maximum Force
0	12.39
1.58	14.43
2.45	17.3
3.95	18.15
4.9	19.5
6.3	22.21
7.33	23.4
8.63	25.76

Figure 14: Max Force Required Vs Angle of Inclination

Section 4: Conclusions

Section 4.1: Temperature Experiment Conclusion

After performing the temperature experiment to determine how long the grill takes to reach a temperature that one can handle safely without personal protective equipment, the following conclusions were made. The first conclusion regards the temperature difference between the lid and base of the grill. After analyzing the results from the experiment, one can observe that the lid exhibits a lower temperature than the base portion of the grill. These results are what appear to be reasonable because the charcoal lies in the base of the grill, therefore heating the surrounding metal more than the lid. Another observation made during the experiment is the fact that the grill took 143 minutes to reach a safe handling temperature. The

first portion of the grill to reach a safe handling temperature was the lid. An item of concern with this experiment is that the grill lid was left closed during the cooling process. The experiment was also performed in an ambient temperature of 33 degrees Fahrenheit. Because this is cooler than the typical ambient operating temperature (grilling will mostly occur during the summer months), it was decided that better results could be obtained from this experiment if it were to be conducted in ambient conditions more representative of the actual operating environment.

## Section 4.2: Lever Force Experiment Conclusion

This experiment yielded results which have been used to decide which lever arm is optimal for use in the intended application. Although the 18 inch lever exhibited the highest force needed to move the table, the 24 inch arm was only a pound less and added an extra four inches of travel. The 30 inch arm showed the lowest force needed to pump the table cart but required an additional eight inches of travel over the 18 inch handle. Therefore, it has been concluded that the 18 inch lever arm is the proper choice for our application. At the cart's highest load the 18 inch handle required a force of approximately 26 pounds to operate. A study done by NASA in 2008 determined various human performance capabilities. This study showed that a female can provide a pushing force anywhere from 43 pounds to 94 pounds. This validates the 18 inch handle as a feasible option for the intended application.

Section 4.3: Slope Force Experiment Conclusion

The purpose of the slope lab was to measure the force required to move our grill at various slopes. The grill has not been completed, so it was decided to load the lift cart to the projected grill weight, 152 pounds, and then measure the force to pull that cart up various slopes. The slope of the ramp was varied from 0-8°, recording the force required to hold the cart in place, then the force required to move the cart. The force required to move the cart is also known as the force required to overcome static friction, and is the peak force on all of the data. The maximum force required to move the grill is 26 pounds and occurred at a slope of about 8°. Comparing this to the NASA human performance study, the 26 pounds required to
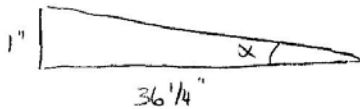
move our cart is well under the maximum pushing force threshold for females of 43 pounds, making the design acceptable.

Appendix A: Hand Calculations

ME 488
Slope Lab hand calcs
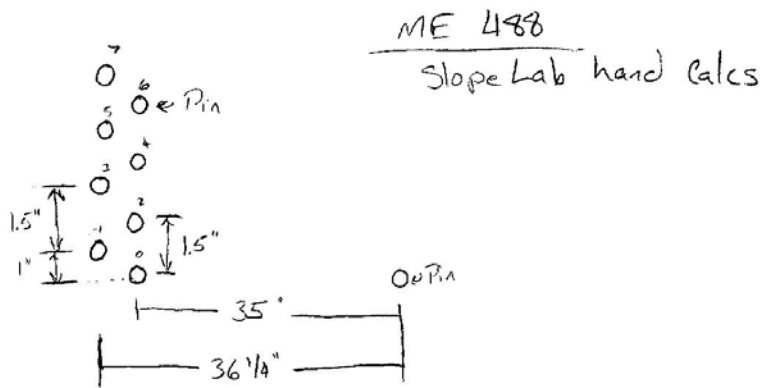
hole 0 → 0°

hole 1 → 1.58°

$$x = \tan^{-1}\left(\frac{1}{36\frac{1}{4}}\right) = 1.58°$$

hole 2 → 2.45°

$$x = \tan^{-1}\left(\frac{1.5}{35}\right) = 2.45°$$

hole 3 → 3.95°

$$x = \tan^{-1}\left(\frac{2.5}{36.25}\right) = 3.95°$$

hole 4 → 4.90°

$$x = \tan^{-1}\left(\frac{3}{35}\right) = 4.90°$$

hole 5 → 6.30°

$$x = \tan^{-1}\left(\frac{4}{36.25}\right) = 6.30°$$

hole 6 → 7.33°

$$x = \tan^{-1}\left(\frac{4.5}{35}\right) = 7.33°$$

hole 7 → 8.63°

$$x = \tan^{-1}\left(\frac{5.5}{36.25}\right) = 8.63°$$

Appendix B: Contributions

Colin Harris:

- Typed conclusion for Lever Force Lab
- Typed conclusion for Temperature Lab
- Contacted company to obtain a working cart so the experiment could be performed
- Assisted in conducting slope lab experiment and temperature lab experiment
- Devoted several hours to figuring out how new load cell worked
- Took pictures of labs conducted to use in experiments

Daniel Shapiro:

- Wrote abstracts and introduction sections
- Assembled, edited, and formatted final report
- Assisted in running of temperature and slope labs
- Generated schematics for procedure sections
- Gave group presentation on experiments to class

Aaron Shelly:

- Contacted customer about using her grill for temperature experiment
- Acquired type K thermocouples and digital reader for temperature experiment
- Acquired material and fabricated the handle for the lever force experiment
- Load Cell related work
- Learned how to use and setup data acquisition software
- Wrote MATLAB programs to refine noisy load cell output signal
- Used said MATLAB program to analyze all data for the lever force and incline force experiments
- Created all plots for the lever force and incline force experiments

Colton Shoemaker:

- Built adjustable platform for slope test
- Participated in all three tests
- Gathered raw data for lever force and slope test on my laptop
- Wrote the original lever force procedure
- Wrote the original slope lab conclusion
- Used personal truck to pick up customer's grill used for the temperature lab
- Took pictures for documentation of all three labs
- Performed hand calculation for slope lab

Shad Williams:

- Wrote the procedure for Incline Force experiment.

- Collect results for Temperature experiment.

- Produced graphs and tables for Temperature experiment.

- Help with Temperature experiment, Force experiment, and Incline Force experiment.

Appendix C: MATLAB Programs

readData.m

```matlab
function [ dataSet, numSamples ] = readData( filename )
%readData This function will take data collected by --- and it will convert
%the string data into a set of doubles that can be used in matlab.  The
%input to readData is the string file name.  The outputs are an array
%containing the numerical values of the voltages measured and a count of
%the number of samples.  Example
%
%   filename = 'TestVoltages.dat';
%   [dataSet, numSamples] = readData(filename);
%

fid = fopen(filename);


%Remove header data
for i = 1:7
   fgetl(fid);
end

numSamples = 0;
while ~feof(fid)
    val = 0;
    temp = double(fgetl(fid)); %Fetch next line in the file
    %Determine the power to be using in converting the string to a double
    %value
    powerof = -(temp(length(temp)) - 48);
    %Converting the string retrieved from the file into a double value
    val = (temp(length(temp)-3) - 48) * 10^(powerof-7);
    val = val + (temp(length(temp)-4) - 48) * 10^(powerof-5);
    val = val + (temp(length(temp)-5) - 48) * 10^(powerof-4);
    val = val + (temp(length(temp)-6) - 48) * 10^(powerof-3);
    val = val + (temp(length(temp)-7) - 48) * 10^(powerof-2);
    val = val + (temp(length(temp)-8) - 48) * 10^(powerof-1);
    val = val + (temp(length(temp)-10) - 48) * 10^(powerof);
    if temp(1) == 45
        val = val * -1;
    end
    dataSet(numSamples + 1) = val;
    numSamples = numSamples + 1;
end


fclose(fid);


end
```

```
forceCalc.m

clear all
format long
filename = '18_225.dat';
[dataSet,numSamples] = readData(filename);

k = 100;
j=1;


%Compensating for offset voltage, averaging, and converting to force (lbs)
B = dataSet - 4.650286302814812; %NOTE: MUST COPY-PASTE Avg value from
zeroFinder
for i = 1:k:numSamples;
    G(j) = mean(B(i:i+(k-1)));
    j = j+1;
end
R = (6.85/4.117)*(B*1000);   %Unaveraged force transformation
F = (6.85/4.117)*(G*1000);   %Averaged force transformation

%Plots of raw and averaged force data
% figure(1)
% plot(R)
% title('Raw Force vs. Time')
% xlabel('Time')
% ylabel('Force (lbs)')

figure(1)
plot(F)
title('Averaged Force vs. Time')
xlabel('Time')
ylabel('Force (lbs)')

% figure(3)
% plot(B)
% title('Raw Voltage vs. Time')
% xlabel('Time')
% ylabel('Voltage (V)')
```

Appendix D: References

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Appendix D

1. OU BBQ Grill Manual

OU BBQ
Grill Manual

Table of Contents:

Replacement Parts:

Paint:
    Red – Valspar Satin Interior/Exterior spray paint, *Wine Red*, model number 65012. This can be purchased at your local Lowes store.
    Black – Char Broil Black Grill Paint, *Black*, model number 4654. This can be purchased online at www.thepartsbiz.com.

Grill Grates:
    Brinkman gas grill grate porcelain coated cast iron cooking grid set of three. Model number 68553, these can be purchased online at www.thepartsbiz.com.

Tie Down Strap:
    Replacement straps can be purchased at any hardware store, such as Lowes.

Thermometer:
    BBQ Pro Temp Thermometer item number BBQ-P-T-1-2.25-2.5. This can be purchased online through www.kck.com or online directly at www.bbqprotemp.com.

Hydraulic Cart:
    Northern Industrial Hydraulic Table Cart – item number 143654. This can be purchased online at www.northerntool.com.
    NOTE: The hydraulic cart installed on your vehicle has been modified from its original form for its use.

Grill Modes:

Transportation Mode:
    In this mode the grill is attached to the back of the truck by two locking pins and one tow strap. The hydraulic lift handle, the aluminum legs, the aluminum leg support, and the rake are all in their stored positions. During this mode the truck can be driven freely, thus transporting the grill from point A to point B.

Cooking Mode:
    In this mode the grill has been removed from the truck. Please read the section labeled "Operation" to see step by step instructions on how to get from Transportation Mode to Cooking Mode. During cooking mode the grill legs and support have been attached and the grill has been moved to a safe distance from the truck for operation.

Grill Parts:

Here you will find a list of the various parts that make up your OU-BBQ grill and bumper.
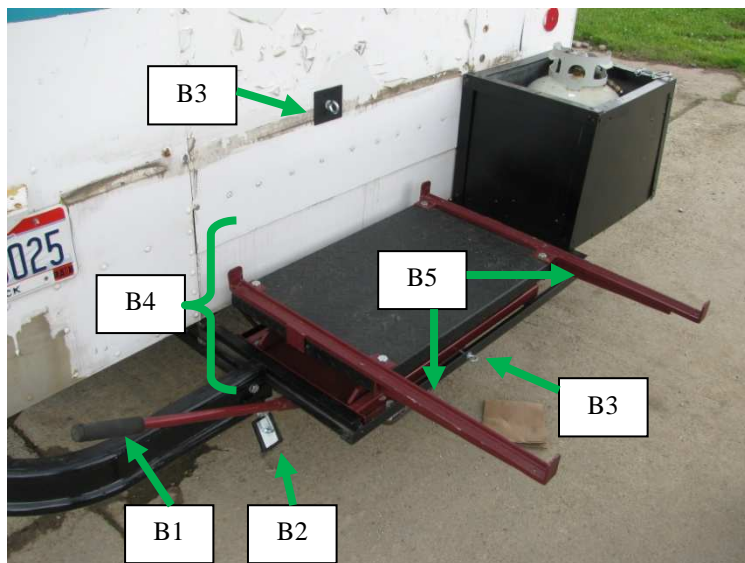

Figure 1 – Bumper Assembly

Reference #	Description
B1	Lift Handle
B2	Release Pedal
B3	Eye Bolts
B4	Hydraulic Lift Cart
B5	Rail System

Table 1 – Bumper Description
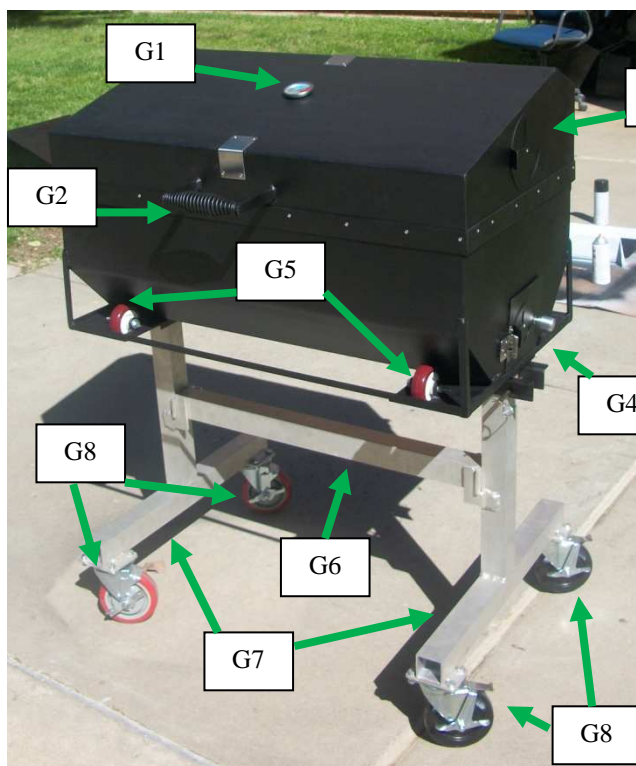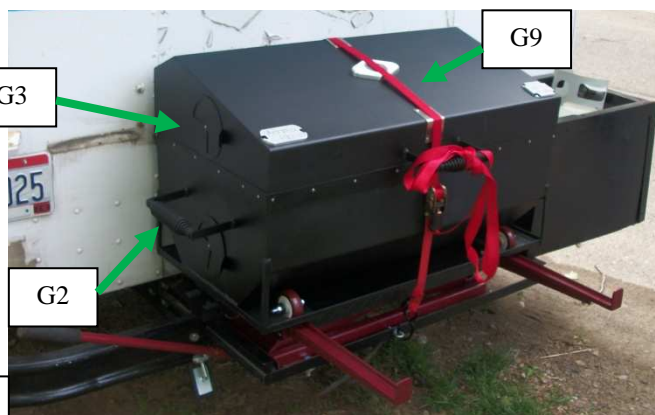
Figure 3 – Grill and Bumper Assembly

Figure 2 – Grill Assembly

Reference #	Description
G1	Thermometer
G2	Handle
G3	Air Vents
G4	Ash Door
G5	Grill Wheels
G6	Aluminum Support
G7	Aluminum Legs
G8	Caster Wheels
G9	Tie Down Strap

Table 2 – Grill Description

Operation

Unloading:

This section will cover the steps required to unload your OU BBQ grilling system. This is the transition between Transportation Mode and Cooking Mode. Figure below illustrates the OU BBQ grilling system in the Transportation Mode.

WARNING

This system was not designed to be operated (cooking) while still on the back of the truck. You must follow the procedure to transition from Transportation Mode to Cooking Mode.

Figure 4 – Transportation Mode

Step 1: Loosen and remove the tie down strap.

Step 2: Retrieve the hydraulic lift handle from the stored position, insert handle into cart and pump cart all of the way up.

Step 3: Remove both locking pins from grill.

Step 4: Using the hydraulic release handle, lower the lift cart until the grill base is just below the top of storage box on the left of the grill unit.
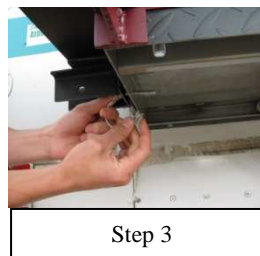
Step 5: Retrieve the aluminum legs and aluminum support from stored positions. (Not pictured)

Step 1

Step 2

Step 3

Step 4

Step 6: Slide the left side leg assembly in place on the base of the grill, **INSERT** the brass locking pin.

Step 7: Slide the right side leg assembly in place on the base of the grill, **INSERT** the brass locking pin.
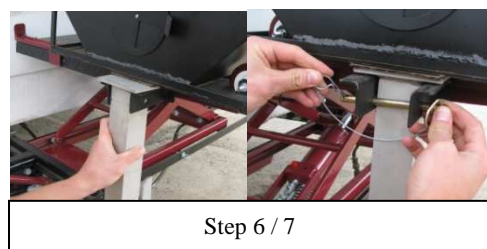
Step 8: Slide the aluminum support down between the left and right leg assembly.

Step 9: Using the hydraulic release handle, lower the lift cart all of the way.

Step 11: Pull straight back so that the legs and grill clear the red rails.

Step 12: Lock each caster to prevent the grill from rolling away while cooking.

Step 13: Begin your barbeque!

Step 6 / 7

Step 8

Step 9

Step 10

Step 11

Cooking:

Figure 5 – Cooking Mode

Step 1: Make sure that the grill is in a safe location for use; lock the caster wheels to prevent motion of the grill.

Step 2: Remove one or more grill grates and add fresh charcoal to the charcoal bed.

Step 3: Light charcoal and let charcoal burn.

Step 4: Once safe, replace the removed grill grates.

Step 5: Use the four air vents to control the temperature of the grill.

Step 6: Place food and begin cooking!

Loading:

This section will cover the steps required to load your OU BBQ grilling system. This is the transition from Cooking Mode to Transportation Mode.

Figure 6 – Loading the Grill

CAUTION

Be sure the grill is cool to the touch before handling.

Step 1: **MAKE SURE** the grill is extinguished and cool to the touch for safe handling of the grill.

Step 2: Unlock the caster wheel, move the grill toward the rear of the truck.

Step 3: Rotate the grill so that the front of the grill is facing out away from the rear of the truck.

Step 4: Make sure that the hydraulic lift cart is in the down position, and that the red rails are free and clear of all debris.

Step 5: Position the grill, and then move the grill so that it is over top of the lift cart. Be sure that the red rails are below the red wheels on the grill as seen in Figure 6 – Loading the Grill.

Step 6: **SLOWLY** raise the table top by pumping the lift handle.

CAUTION

Be sure that the tie down strap rests on the stainless steel plates.

Step 7: Continue to raise the lift cart just until the grill legs are no longer touching the ground. Be careful not to raise the grill too high with the legs attached, they will crash into the bumper unit.

Step 8: Remove the aluminum support between the legs and then remove the legs.

Step 9: Push the grill back as far as it will go. Replace the security/locking pins that were removed in Step 3 of the Unloading Procedure.

Step 10: Slowly lower the hydraulic cart by depressing the release handle. Make sure that the cart is in the complete lowered position before proceeding.

Step 11: Replace the tie down strap and tighten the strap to secure the grill in place. **Do not** over tighten the tie down strap.

Step 12: Clean up and drive safe!

Maintenance:

In order to ensure that your OU BBQ grill operates correctly please follow this maintenance plan.

During each use:
- Inspect your tie down strap, be certain that the strap is not frayed or coming apart. Also check to make sure that the strap stays tightened.
- Inspect the entire assembly, making sure that there is no debris in the linkage for the hydraulic lift or in the red rails preventing correct motion of the grill unit.

Periodically:
- Inspect all nuts and bolts; please tighten if they appear to be loose.
- Inspect all welds; contact a licensed professional if cracks or damage is present.
- Clean and touch up any rust spots with the appropriate paint.

Cleaning:
- Use mild soap and water to clean the grill and bumper assembly.
- Do **NOT** use any chemicals such as bleach or any solvents such as rust prevention. These chemicals can be harmful to the paint and not food safe.

Painting:
- Apply touch up paint in a timely manner to help prevent rust.

   For best results-
- Use medium grit sandpaper and sand away all rust.
- Dampen a dry and clean cloth with some mineral spirits, or paint thinner, wipe sanded spot clean of all dust and dirt.
- Allow the area time to dry.
- Apply the touch up paint as needed (one to two coats).

Troubleshooting:

*The lift cart will not rise when pumping the lift handle.*
   Check to be sure that the release pedal is not active.
   Make sure that there is no debris stuck in the linkage of the hydraulic cart.

The aluminum support piece for the legs will not fit.
   Check to be sure that the aluminum tabs on the legs are not bent. If so, straighten them back out with a set of pliers. (See picture to the right)

The ash door will not open and close properly.
   Inspect the clasp on the inside of the door.
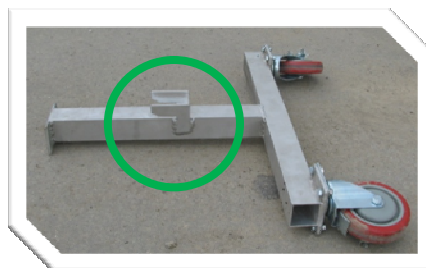
Troubleshooting (Continued):

The tie down strap is not working correctly.
> If the strap is stuck on the grill and will not come off, then you can carefully cut the strap off. The strap will need to be replaced before transporting the grill.

The grill will not roll when in Cooking Mode.
> Check to be sure the caster wheels are unlocked.
> Check to be sure the caster wheels are free of debris.

The locking/security pins will not fit.
> Make sure that the holes for the pins are lined up correctly. You may need to move the grill around to get the holes to line up correctly.

The lid will not open and or close properly.
> Check the flashing on the lid. The flashing is the sheet steel that overhangs the bottom of the lid. The flashing could be bent preventing the lid from closing all of the way. If bent, use pliers to bend the flashing back in place. The flashing can also be removed by drilling out the rivets that hold it in place.

May 8, 2010
Senior Design Demonstration Day